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ABSTRACT

This manual provides a detailed simulation analysis of a variety of energy conservation measures (ECMs) with the intent of giving educational facility design teams in Florida a basis for decision making. The manual's three sections cover energy efficiency design considerations that appear throughout the following design processes: schematic design; design development; and systems design. Designers are advised to aim for the lowest consumption building that is economically possible and to target the major energy users, i.e. lighting and air conditioning, to achieve that goal. Reductions in annual energy use, energy cost, and cooling capacity are provided for comparing relative performance of ECMs. Simple payback of ECMs appears in a chart in each section's overview; life cycle cost savings appear in the conclusions section. An appendix describes the energy simulation program used in the manual to predict energy savings. Case studies are included. (Contains 45 references.) (GR)

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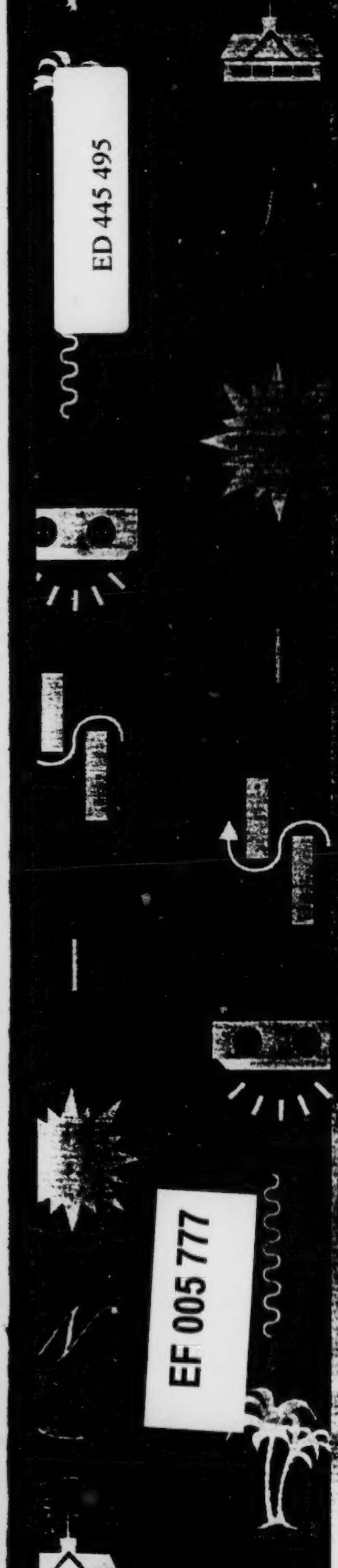
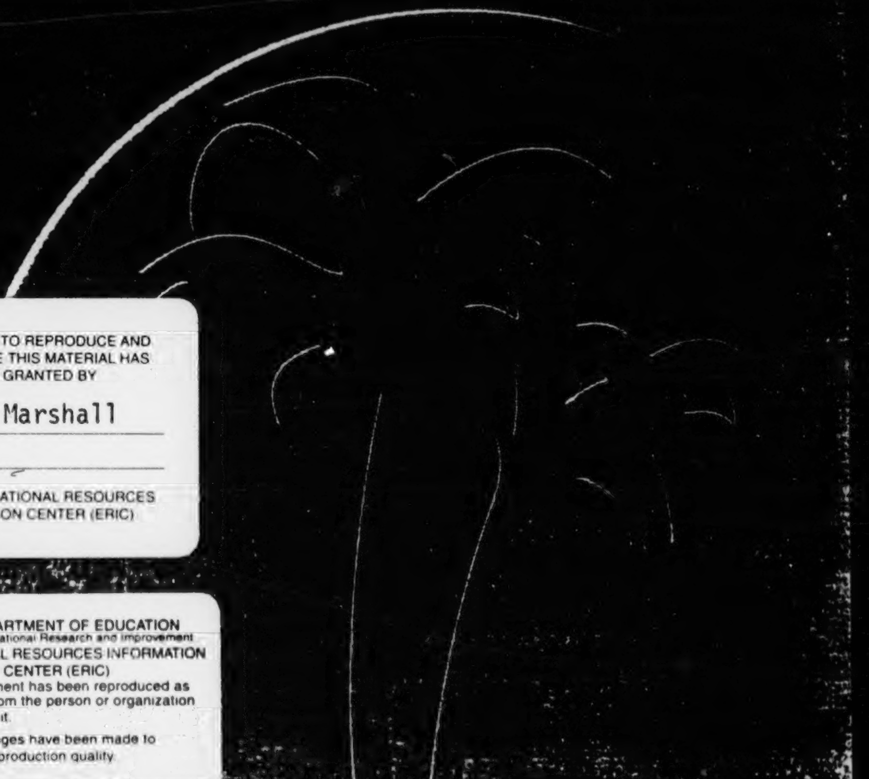
Energy-Efficient Design for Florida Educational Facilities

Florida Department of Education





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Energy-Efficient Design for Florida Educational Facilities

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ACKNOWLEDGEMENTS

The **Building Design Assistance Center (BDAC)** researches building energy efficiency concepts for Florida. It is a part of the Research and Development Division at the **Florida Solar Energy Center**.

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FOREWORD

Reducing energy use in Florida's schools is a matter of great importance. In general, energy expenses makes up 14 - 15%* of a typical facility's total costs of operation. These matters are all the more important as many design teams and school boards look for ways to meet new ventilation standards which loom on the horizon and exacerbate the existing energy design challenges. And perhaps most importantly, these funds, which are spent on energy services, are unavailable for more pressing needs to improve our schools.

To address this critical task the Florida Department of Education sponsored a research team at the Florida Solar Energy Center (FSEC) along with several consultants to produce a training manual which comprehensively addresses energy efficient design of new educational facilities. This manual represents the culmination of an intensive work schedule by a number of dedicated individuals over a 18-month period to produce a manual that considers our state's unique climatic circumstances. Rather than another paper study, our intent has been to produce a useful training and reference resource prepared for the design team to aid them in incorporating energy efficiency into new building design with the least possible effort and in the most cost-effective manner.

The current version represents the status of our work in the summer of 1994. As this is the first edition, the manual should be viewed as an evolutionary document. The Florida Department of Education plans to incorporate new information and user feedback into the various sections of the manual as such information becomes available. Users who return the registration card will automatically be informed by mail of any revisions. Updates will be issued for specific sections of the manual as they become necessary. We are very interested in suggestions and comment or correction on the manual's content. Although, our research team has endeavored to create a balanced and accurate assessment of available technologies, with an analysis as comprehensive and ambitious as this one, errors of fact or omission are inevitable. We ask that readers contact us to point out any deficiencies they encounter. Beyond correction, we are particularly interested in user experiences in applying the technologies described and/or in applying the overall design process described in the manual to entire facilities.

It is our sincere desire that this manual will assist you in planning successful projects to reduce energy use in Florida schools in a cost-effective manner while providing an enhanced learning environment for tomorrow's students and instructors. Working together, we can make a difference.

Janet E.R. McIlvaine
Cape Canaveral, July, 1994

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* Excluding capital outlay, salaries, benefits, and transportation.

Table of Contents

Page

Foreword ... i

Introduction ... 1

Section I -- Schematic Design ... 9
- Overview ... 11

- Energy Strategies:

    - Optimal Orientation ... 17
    - Building Configuration ... 22
        - Consensus Recommendations ... 27

Section II -- Design Development ... 29
- Overview ... 31

- Energy Strategies:

    - Glazing Selection ... 41
        - Consensus Recommendations ... 47
    - Window Shading ... 49
        - Consensus Recommendations ... 56
    - Enhanced Envelope ... 57
        - Consensus Recommendations ... 66

Section III -- Systems Design ... 67
- Overview ... 69

- Energy Strategies

    - Efficient Lighting ... 74
        - Consensus Recommendations ... 88
    - Efficient HVAC ... 89
        - Consensus Recommendation ... 121

Conclusions ... 125

References and Bibliography ... 149

Glossary ... 157

Case Studies ... 165

Appendix A: Simulation ... 173

Description

This document provides a detailed simulation analysis of a variety of energy conservation measures (ECMs) with the intent of giving design teams a basis for decision making. Designers are advised to aim for the lowest consumption building economically possible and to target the major energy users, lighting and air conditioning, to achieve that goal.

Reductions in annual energy use (kBtu/SqFt), energy cost ($), and cooling capacity (tons) are provided for comparing relative performance of ECMs. Simple payback of ECMs appears in a chart in each section's *Overview*. Life cycle cost savings appear in the *Conclusions* section.

Mission

This manual addresses energy efficiency options for new educational facilities in Florida. The recommendations may not be valid when considered outside Florida's hot humid climate or for purposes other than new construction.

Construction funds spent on new construction heavily outweigh (67%) those spent on retrofit, as reported in an annual statistical analysis published by *American School and University* (September 1992). The comprehensive survey showed that construction funds for new educational facilities nationwide have risen for eight consecutive years, and no region has experienced more growth than the Southeast. Currently, funds spent on energy services (excluding capital outlay, salaries, benefits, and transportation) account for about 14% of the current expenditures (i.e., operating cost) in Florida schools (Eggers, 1994). Data represented in this work shows that for a new facility, energy consumption can be reduced by 43% compared to current construction and design practices with a cumulative life cycle saving of $260,322 for a single classroom building.

As a matter of public responsibility, the Florida Department of Education (DOEd) encourages designers to carefully consider the potential operating savings of available ECMs.

Introduction

Audience

This manual has been written for all members of the design team, including school board members, educational facilities planners, architects, and engineers. Both the expert and novice are served by this manual as it includes information on new technology and research as well as the basics of building energy use.

Understanding the "big picture" is paramount in energy efficient design. Readers are encouraged to review the section *Overviews* and energy *Strategy* summaries as a unit. With a clear understanding of how the various aspects of design affect the building as an *energy using system*, readers will find that the best choices become more obvious.

This manual has been written to provide reliable, non-biased information on ECMs. Although the simulation studies in this manual represent general building types, they offer a comprehensive comparison of energy design options for Florida's new educational facilities.

> As with all subjects, the more one learns, the more questions arise. Readers may address inquiries to:

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BBS: (407)730-BDAC Attn: JERM

Priorities

Each new school design must satisfy a variety of requirements, with safety and education obviously having top priority. Energy conservation strategies and technology must never compromise the safety or the quality of an educational environment. Measures which compromise education to save money are a false economy.

Design teams should consider school safety issues such as evacuation, emergency shelter functions, unauthorized access, vandalism, and theft when an ECM is being assessed. Questions such as the following should be considered:

- *How will this ECM at this facility affect the basic functions of the school?*
- *If this measure or device is damaged by wind or lightning, will it disrupt normal school operation?*
- *Will this ECM impede proper evacuation in an emergency?*
- *Will this ECM allow inappropriate access to any part of the facility, such as the roof, courtyards, etc.?*
- *Will this strategy facilitate vandalism or provide vandals with cover?*

Another critical priority is cost. Schools must be built, operated, and maintained within an allotted budget. Design teams must weigh the first cost of ECMs against annual or lifetime savings. While ECMs reduce energy consumption and operating costs, they often cost more than conventional practices. Furthermore, maintenance costs should be kept in mind. Design teams should pose questions such as:

- *Can the regular operations staff maintain this ECM? If not, is reliable service available for this product or equipment?*
- *How often will this ECM need service and how will that affect the normal maintenance schedule of the school?*
- *If an ECM requires outside maintenance service, will the cost outweigh operating savings?*
- *When will this ECM have to be replaced?*

Cost Effectiveness

The cost effectiveness of an ECM can be evaluated in a variety of ways. Simple payback and life cycle cost analysis are two commonly used methods. Life cycle cost savings for each ECM appear in the *Conclusions* section, Tables 1-3. Life cycle cost analysis has not been performed for scenarios where two or more ECMs have been considered at the same time.

Annual energy cost savings for each ECM or combination of ECMs appear in the body of the manual. This method of cost effectiveness evaluation does not satisfy the Department of Education's life cycle cost analysis requirements. It only provides a method of comparing the relative performance of different ECMs.

Energy Analysis Methodology

Likewise, the energy saving potential of an ECM can be evaluated in different ways. The method chosen for this analysis is a comprehensive computer simulation tool called *DOE 2.1D*, a building energy simulation software developed by the U.S. Department of Energy and Lawrence Berkeley Laboratory. The techniques used to estimate potential energy savings of the ECMs in this manual are similar to the methods used in energy efficiency research throughout the United States.

Three building types were selected for study:

- a classroom building
- an administrative building
- a multipurpose assembly building.

These commonly appear on the campuses of elementary and secondary schools in Florida. (Larger, more complex versions of these buildings can be found on community college and university campuses.)

The physical characteristics of these three building types were modeled using *DOE2.1D* and are referred to as Base Case Buildings.

Next, the characteristics of the Base Case Buildings were changed to simulate the effect of each ECM on the building's cooling capacity, energy use, and energy cost.

Last, these figures for each of the ECMs were compared to the Base Case figures. Those measures that lowered energy use or energy cost were then evaluated for cost effectiveness (using life cycle cost analysis).

Two sets of input data were required to execute the simulations for each building type: one set of physical and operational characteristics for each building type and a set of characteristics for each ECM. The characteristics used to model the building types came from

- blueprints of recently built schools
- discussions with architects and engineers
- discussions with school operations staff
- site visits to new schools.

Characteristics used to model the ECMs came from measured laboratory or field data, engineering handbooks, discussions with experts in building energy efficiency, or predefined options available in *DOE2.1D*. Appendix A, *Simulation*, documents the detailed assumptions on all data.

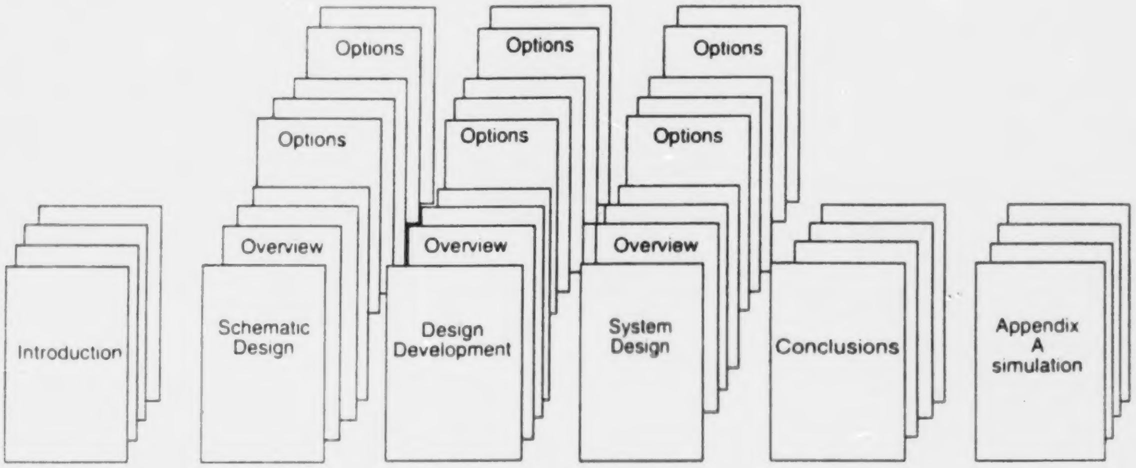
Organization of the manual

Manual: The format of the manual emphasizes that energy efficiency should be considered throughout the design process. It is divided into three sections (Figure 1).

- *Section I* discusses Schematic Design energy strategies.

- *Section II* discusses Design Development energy strategies.

- *Section III* discusses System Design energy strategies.


Options
Options
Options
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Options
Options
Overview
Overview
Overview
Introduction
Schematic Design
Design Development
System Design
Conclusions
Appendix A simulation

Figure 1. **The bulk of the manual is housed in three main sections: Schematic Design, Design Development, and System Design.**

Sections: Each of the Sections begins with an *Overview* of the energy saving strategies appropriate for that design phase. After the overview, *energy conservation strategies* (Figure 2) are presented. Each strategy's objective and considerations are summarized and *ECM Options* (specific ways of accomplishing a strategy) are listed.

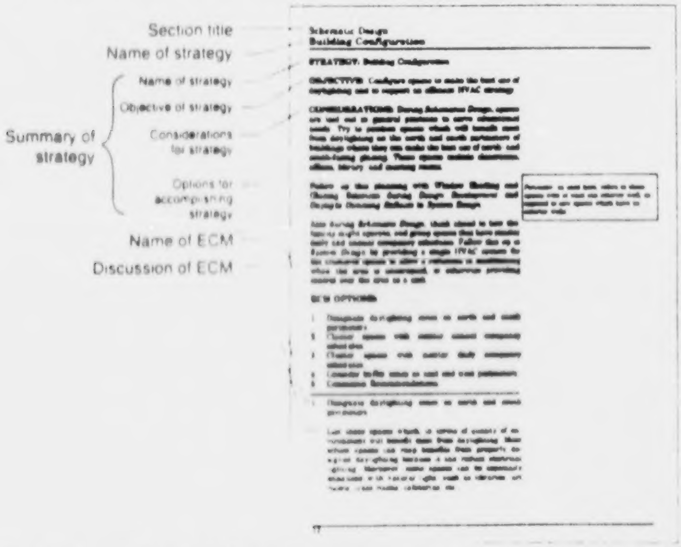
Section title
Name of strategy
Summary of strategy
Name of strategy
Objective of strategy
Considerations for strategy
Options for accomplishing strategy
Name of ECM
Discussion of ECM

Figure 2. **For each energy conservation strategy a summary of the objective, considerations, and ECM option is given before each ECM option is discussed.**

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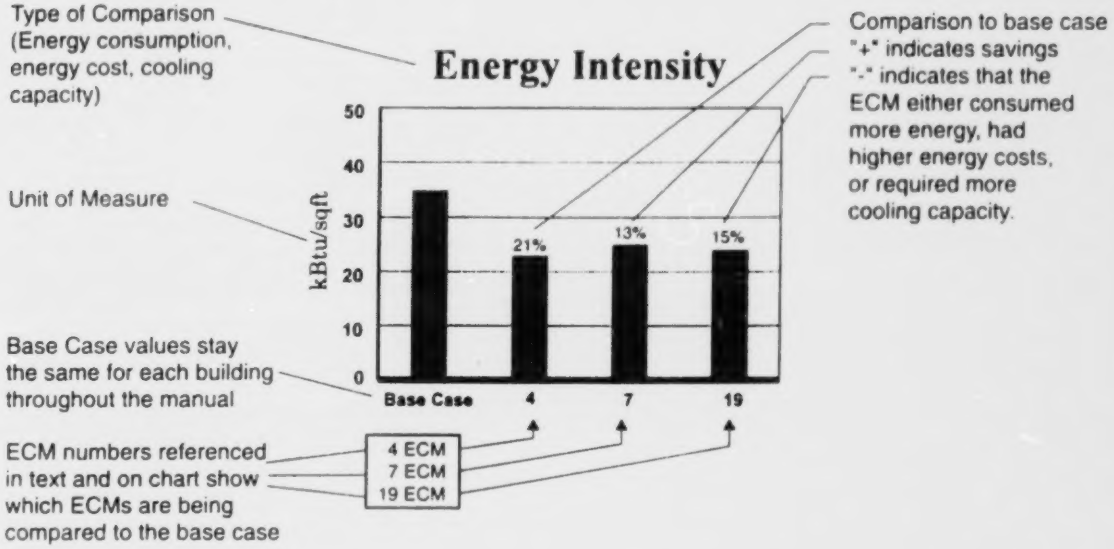
ECMs: Each ECM option is discussed separately, and simulation data on annual energy consumption (kBtu/SqFt), annual energy cost ($) and cooling capacity (tons) are presented as bar charts (Figure 3). For assistance in interpreting this data, readers may contact the Building Design Assistance Center (address on page 2).



Type of Comparison (Energy consumption, energy cost, cooling capacity)

Unit of Measure

Base Case values stay the same for each building throughout the manual

ECM numbers referenced in text and on chart show which ECMs are being compared to the base case

Comparison to base case "+" indicates savings "-" indicates that the ECM either consumed more energy, had higher energy costs, or required more cooling capacity.

Figure 3. **Simulation results are presented as bar charts for comparing performance different ECMs.**

Reporting Errors

Researchers diligently reviewed all building input data and simulation results to ensure accurate representation of real life; however, should an error or inaccurate assumption be detected, readers are requested to inform the Office of Facilities at the Florida Department of Education or the Building Design Assistance Center at the Florida Solar Energy Center (see contacts page 2) so that other users of this manual can be notified.

Section I

Schematic Design

During the *Schematic Design* phase, design teams should strive to:

1. Establish financial parameters.
2. Select energy conservation strategies.
3. Incorporate optimal building orientation.
4. Consider advantageous building configuration.

Schematic design decisions have a lasting impact on building energy use and the effectiveness of energy conservation measures (ECMs). At this point in the design process, the design team should loosely decide which ECMs are likely to be used and plan for their implementation.

Establish Financial Parameters

Design decisions should be based on realistic financial and energy savings expectations. The energy savings data in this manual (given in kBtu/SqFt) can be coupled with current utility, materials, and installation costs to establish a simple payback or life cycle cost. Life cycle savings for 1993-94 costs for each ECM appear in *Conclusions*, Tables 1-3. Additionally, an economic optimization based on life cycle savings appears in the *Conclusions* section. There, we also include optimization analysis showing the highest performance group of technologies as well as the predicted most cost effective package of options.

When referring to the cost evaluations in this manual, design teams need to consider whether or not the Base Case Building (described in Appendix A) is similar to the building in question and make allowances for any differences. As much detail as possible regarding the energy savings and cost data used to produce the economic evaluations in this manual have been included in Appendix A. If a school design closely matches the Base Case Buildings (described generally in the *Introduction* section and in detail in Appendix A), the economic analysis provides a good basis for decision making.[1]

---

[1] The Building Design Assistance Center has been funded by the Florida Energy Office to provide the Florida design and engineering community with free energy efficiency evaluations for commercial buildings, including computer modeling of specific buildings similar to those conducted for this manual For information on how to obtain analysis for a specific building project, contact Janet McIlvaine, BDAC Educational Facilities Contact, Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, FL 32920

Schematic Design Overview

During *Schematic Design*, an acceptable length of payback or other financial criterion needs to be established to aid the design team in selecting ECMs. When design teams have a clear idea of how much money can be allocated to ECMs and how quickly it must be recouped, selecting ECMs for a specific project will be simplified. A required period of payback may have already been established by the facilities office of the district or campus.[2]

Select Energy Strategies

To achieve the greatest success, design teams should select energy strategies early. Planning should certainly begin during *Schematic Design* for those energy strategies that depend on the relationship of the building to the sun's path. For example, if the design team waits until *Design Development* to try incorporating a daylighting strategy, then the basic building orientation and configuration may not support effective daylighting.

This need for early planning holds true not only for strategies related to orientation but also for items such as occupancy sensors, energy management systems, and more efficient Heating, Ventilating, and Air Conditioning (HVAC) equipment. These strategies should be selected early so that implementation, financing, and maintenance issues can be fully explored, and appropriate spatial or relational allowances in the site and floor plan can be made during *Schematic Design*.

To properly select energy strategies, the design team needs to understand the typical energy use characteristics of educational facilities in Florida.

- What are the major uses of energy in school facilities?
- What are the components of those uses?

Energy end-uses

The major uses of energy, or *end-uses*, related to the services and associated and equipment that consume energy. Statistics compiled for the Florida Energy Office (SRC, 1992) show that the major energy end-uses in educational facilities statewide are HVAC equipment and electrical lighting equipment (Figure 4). The rest of the consumed energy goes to other various end-uses such as water heating, kitchen equipment, office equipment, etc.

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[2] The Florida DOEd currently requires Life Cycle Cost analysis only for the HVAC system

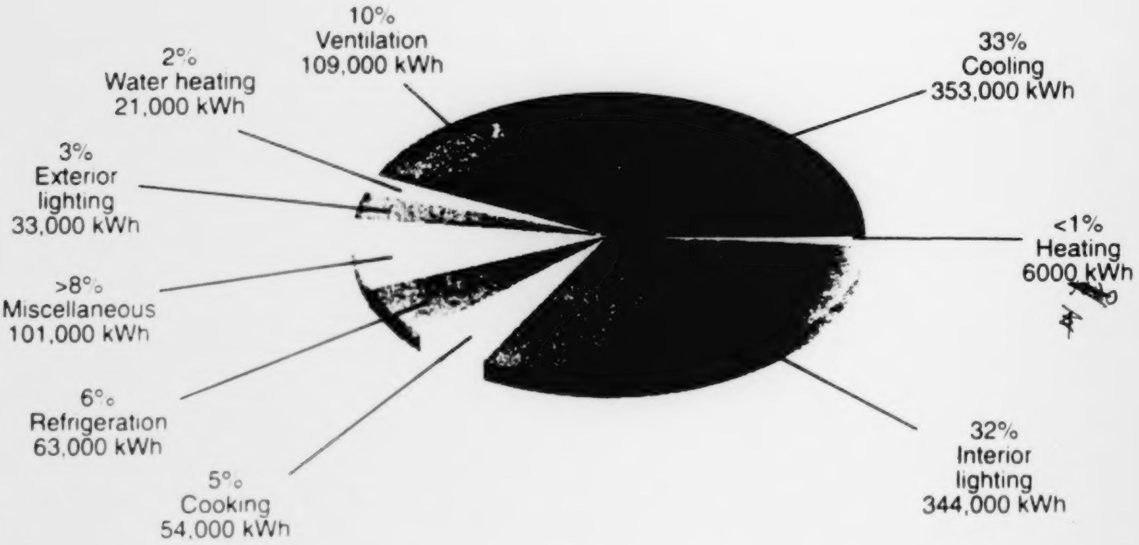

Figure 4. Energy end-use in a typical Florida educational facility.

Energy Loads

The components, or *loads*, of the end-uses are those forces that induce the devices or equipment to use energy. For example, heat produced by occupants is a load on the HVAC system, an end-use. Designers with a clear understanding of energy use characteristics in educational facilities can select more rewarding strategies *by targeting major end-uses and their loads*.

Targeting HVAC and lighting achieves the highest energy savings; so, throughout this manual, many ECMs are discussed in terms of their ability to reduce the consumption of these two key end-uses and their associated loads. The components of the HVAC and lighting loads are discussed below.

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Schematic Design Overview

HVAC Loads: Principally, HVAC systems in Florida use energy to perform three functions: provide ventilation, supply cool conditioned air, and control moisture. The HVAC *loads* is needed to change warm moist, stale interior air and ventilation air into cool, dehumidified air (Figure 5). The major loads on the HVAC system are heat and moisture generated by occupants, lights, and equipment. These *internally* generated loads can often be effectively reduced.

Other *externally* gained loads include heat radiated from the sun to interior surfaces through glazing, heat conducted to the interior by exterior surfaces, and infiltration of unconditioned outside air through the building envelope. Outside air introduced as ventilation air also makes a large contribution to the air conditioning load. Air conditioning consumption can be reduced by either reducing these loads or selecting more efficient HVAC equipment.

Type of Load	Component of Total Load	% of Total Load
Internal Heat and Moisture Loads	Occupants	29
	Lights	15
	Equipment	6
External Heat and Moisture Loads	Walls	1
	Roof	2
	Glass conduction	2
	Glass radiation	7
	Underground surfaces	2
	Infiltration/Ventilation	36

Source: DOE2 1D Simulation Analysis (see Appendix A).

Figure 5. Peak air conditioning load characteristics for a Base Case Classroom Building.

The design team has two fundamental methods for achieving low air conditioning consumption:

- Minimize the HVAC loads and the size of the HVAC equipment.
- Maximize the efficiency of the HVAC equipment.

During *Schematic Design*, the design team can plan ahead for a low-consumption HVAC system by:

- committing to a high efficiency HVAC system
- committing to a low-consumption/high-efficiency lighting strategy
- minimizing east- and west-facing glazing
- committing to energy efficient equipment (refrigerators, computers, printers, etc.)
- planning for heat-rejecting envelope finishes and/or assemblies
- carefully considering an effective ventilation system.

Lighting Loads: Educational facilities have an undeniable need for visual comfort, which is strongly influenced by the distribution and quality of light. A major portion of the electrical lighting load comes from the demand for general lighting throughout the school. Exterior lighting, task lighting, accent lighting and exit signs, and miscellaneous lighting make up the balance of the lighting load.

Lighting systems in educational facilities directly use about 32% of the total annual electrical consumption. Additionally, they are one of the largest loads on the HVAC system, producing about 15% of the peak HVAC load.

When the lighting load decreases, the HVAC load decreases too. This dual role in energy consumption makes lighting ECMs especially attractive. With lighting, design teams can reduce the HVAC and lighting end-uses simultaneously.

Generally the design team has two methods for achieving efficient lighting systems:

- Minimize the run-time of the lighting system.
- Maximize the efficiency of the lighting system.

Schematic Design Overview

During *Schematic Design,* designers can lay the foundation for reducing lighting system run-time by planning for daylighting and occupancy controls. This begins with *Optimal Orientation* and *Building Configuration,* is developed with *Glazing Selection in Design Development*, and is completed with *Electronic Dimming Ballast* in *System Design*. Even without the benefit of a well-planned daylighting scheme, high-efficiency lighting systems and automated lighting controls produced results that ranked among the top performers studied.

Attitude

In reality, any energy conserving strategy selected will ultimately need the attention of every design team member because, from the energy perspective, buildings are systems. All the energy-use elements are interconnected. Everyone on the design team should be aware of the energy goals of the team and understand how his/her contribution to the design relates to those goals.

Strategies for *Schematic Design*

- **Optimal Orientation .... page 17**
- **Building Configuration .... page 22**

		Intensity	Cost	Capacity	Consumptio	Consumption	First Cost	Cost Savings	Payback
	CLASSROOM BUILDING	kBTU/sqft	$	Tons	kWh	Therms	$	$	Years
	Base Case	44	15481	46	186239	103	0	0	0
1	Non-optimal Orientation	45	15726	47	190449	126	0	-245	0

		Energy Intensity	Energy Cost	Cooling Capacity	Electric Consumptio	Gas Consumption	Incremental First Cost	Energy Cost Savings	Simple Payback
	ADMINISTRATION BUILDING	kBTU/sqft	$	Tons	kWh	Therms	$	$	Years
	Base Case	42	9735	25	122670	60	0	0	0
1	Non-optimal Orientation	44	9937	25	125679	74	0	-202	0

		Energy Intensity	Energy Cost	Cooling Capacity	Electric Consumptio	Gas Consumption	Incremental First Cost	Energy Cost Savings	Simple Payback
	MULTIPURPOSE BUILDING	kBTU/sqft	$	Tons	kWh	Therms	$	$	Years
	Base Case	16.15	4068.63	20	509177	418.93	0	0	0
1	Non-optimal Orientation	17.94	4366.11	21	554251	503.52	0	-297	0

STRATEGY: Optimal Orientation

OBJECTIVE: Maximize daylighting potential by orienting major glazing areas, or window, to face south and north. Minimize solar heat gains by having as little wall area and glazing as possible face east and west.

CONSIDERATIONS: In summer, east- and west-facing walls and windows receive direct solar radiation for a longer period each day than south-facing walls. North and south facades receive diffuse and reflected solar radiation for longer periods than the east- and west-facing walls. Diffuse and reflected solar radiation causes less glare and contains less infrared radiation, or heat. Additionally, the shallow sun angles in the east and west sky prove very difficult to shade. From an energy perspective, a good schematic site plan provides north- and south-facing glazing, limits east- and west-facing glazing, and mini-mizes east- and west-facing walls.

Although some perceive daylighting as costly, it can often be a very low cost strategy when planned from the beginning. By making the decision to orient most windows to face north and south, half of the daylighting challenge is met and costs for window shading are effectively minimized.

To fully maximize daylighting success, follow up with Window Shading and Glazing Selection strategies during *Design Development*. This will improve the quality of daylighting in spaces with south-facing glazing by reducing glare and localized overheating. Also follow up with daylight-responsive lighting controls in *System Design* to ensure that available natural light will actually reduce lighting system energy use.

ECM OPTIONS:

1. **Optimal Orientation**

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1. Optimal Orientation

Building orientation determines the buildings relationship with the sun's path. This in turn determines solar gain characteristics of the building and the daylighting potential. If a building's long or major axis is parallel to the east-west axis, then the major

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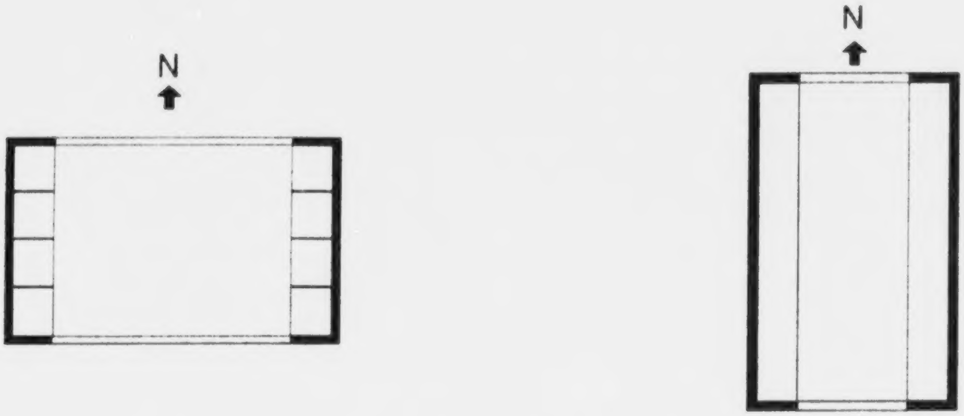
facades and major glazing areas of the building will face north and south. This constitutes Optimal Orientation (Figure 6).



Buffer zones for Optimal orientation

Buffer zones are generally impractical for Non-optimal orientation

Figure 6. Align the long axis of a building with the east-west axis, and position major glazing areas to face north and/or south.

Glazing that faces north will provide the highest quality of daylight and the least amount of heat gain, because the solar radiation does not come directly from the sun but is reflected off of surfaces and diffused through the atmosphere. North-facing glazing places little burden on the HVAC system and provides pleasant light appropriate for classrooms, administrative offices, libraries, and cafeterias.

Glazing facing south, on the other hand, can receive solar radiation directly from the sun. Southern sun brings with it intense heat which causes localized overheating when focused in a small area such as an office, conference room, or the perimeter of a classroom. Additionally, direct southern sun is more likely to cause disability glare (light reflecting from work surface into eyes) than the diffuse or reflected northern sun. Still, this north-south exposure is preferable to the east-western exposure since the south-facing facade will receive direct solar radiation for a smaller portion of the day. The southern exposure of

Optimal Orientation can be much more effectively shaded with exterior elements than the east or west.

Non-optimal orientation, or aligning the long building axis with the north-south axis, carries two penalties. First is the thermal penalty from wall and glazing solar heat gains. East- and west-facing facades receive direct solar radiation for more hours during the day than a south facade and at lower angles (Figure 7). Second is the daylighting penalty. When sunlight comes from a low angle (as it does from east and west), exterior shading becomes very difficult and occupants have to use interior shades to reduce glare and localized overheating. Unfortunately, with interior blinds or curtains the heat, or infrared, portion of sunshine is not stopped from entering the interior space but the visible, or light, portion is interrupted. Therefore, the window does not provide much natural illumination, rendering any daylighting strategy ineffective for the time period that the blinds are closed. Meanwhile, the space still suffers most of the thermal gains. Depending on the shape of the building, that time period will likely be from just after noon until the end of school on the west. And on the east, it will be from mid-morning to just before noon. This would likely reduce daylighting savings from electronic dimming ballasts, for example, by roughly 40%. (These shading issues are discussed further in *Window Shading* strategy in the *Design Development* Section). Exterior shading redirects solar radiation, but more importantly does not disable the daylighting scheme the way interior shading devices do.

Sun Azimuth and Altitude Angles for Latitude 28°

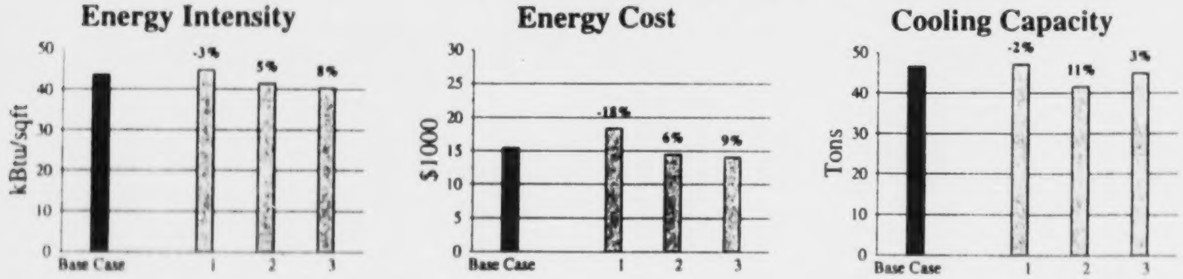
Azimuth	Dec Hours (alt)	Jan/Nov Hours (alt)	Feb/Oct Hours (alt)	Mar/Sept Hours (alt)	April/Aug Hours (alt)	May/July Hours (alt)	June Hours (alt)
60-90					6-7 (0-25)	5:30-9 (0-50)	5:30-9 (0-50)
90-135	8-9 (0-20)	7-8 (0-25)	7-9 (0-38)	6:30-10 (0-52)	7-11	9-11	9-11:15
135-180	9-12 (20-38)	8-12 (25-42)	9-12 (38-50)	10-12 (52-62)	11-2	11-12	11:15-12
180-225	12-4 (38-20)	12-3:30 (42-25)	12-2:30 (50-38)	12-2 (62-52)	12-1	12-1	12-12:45
225-270	4-5 (20-0)	3:30-5 (25-0)	2:30-5:30 (38-0)	2-6 (52-0)	2-4	1-3	12:45-2
270-300					4-6	3-6:30	2-6:30

Note: 90° Azimuth = due East, 180° Azimuth = due South, 270° Azimuth = due West

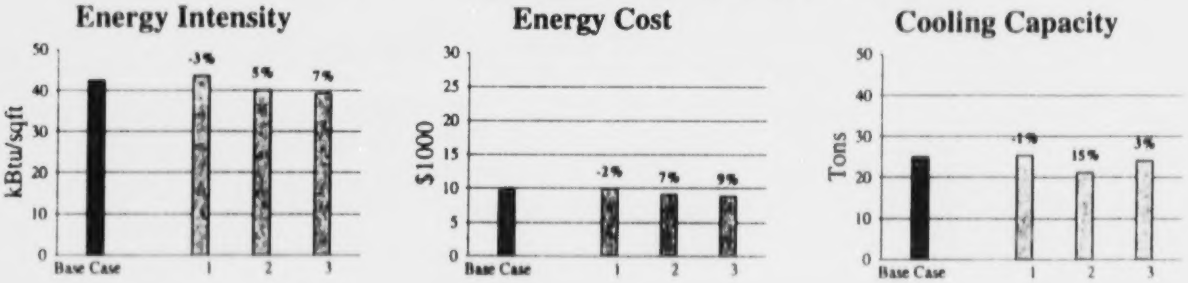
Figure 7. Sun azimuth and altitude (alt) angles for latitude 28° throughout the day and year.

The southern exposure of Optimal Orientation can be much more effectively shaded with exterior elements than the east or west. In the absence of a daylighting scheme, simulations (Figure 8) reveal that non-optimal orientation (#1) has some impact (2-3%) on annual energy consumption due largely to radiant heat gain through glazing. If coupled with an advanced glazing (#2) or a high-efficiency lighting system (#3), this penalty can be overcome, however the localized over-heating and glare challenges associated with east and west facing glazing will remain.

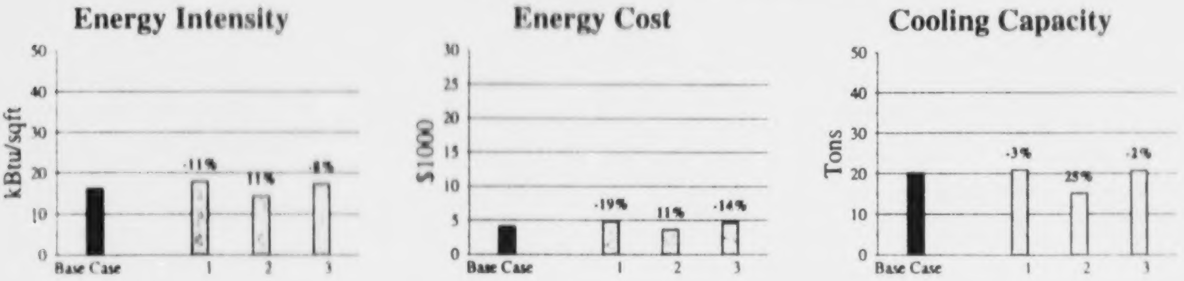
CLASSROOM BUILDING



ADMINISTRATION BUILDING



MULTIPURPOSE BUILDING



1	Non-optimal Orientation
2	Non-optimal Orientation, Double Spectrally Selective Glazing
3	Non-optimal Orientation, T-8 Lamps, Electronic Dimming Ballast

Figure 8. Simulation data shows a penalty of about 2% for selecting non-optimal orientation (#1) compared to the optimally oriented Base Case Building. This penalty can be overcome with other options, but glazing in this position (#2, #3) challenges the success of daylighting strategies.

STRATEGY: Building Configuration

OBJECTIVE: Configure spaces to make the best use of daylighting and to support an efficient HVAC strategy.

CONSIDERATIONS: During *Schematics Design*, spaces are laid out in general positions to serve educational needs. Try to position spaces which will benefit most from daylighting on the north and south perimeters of buildings where they can make the best use of north- and south-facing glazing. These spaces include classrooms, offices, library, and meeting rooms.

Follow up this planning with **Window Shading and Glazing Selection** during *Design Development* and *Daylight Dimming Ballasts* in *System Design*.

Perimeter, as used here, refers to those spaces with at least one exterior wall, as opposed to *core* spaces which have no exterior walls.

Also during *Schematic Design*, think ahead to how the facility might operate, and group spaces that have similar daily and annual occupancy schedules. Follow this up in *System Design* by providing a single HVAC system for the clustered spaces to allow a reduction in conditioning when the area is unoccupied, or otherwise providing control over the area as a unit.

ECM OPTIONS:

1. Designate daylighting zones on north and south perimeters.
2. Cluster spaces with similar annual occupancy schedules.
3. Cluster spaces with similar daily occupancy schedules.
4. Consider buffer zones on east and west perimeters.
5. Consensus Recommendations.

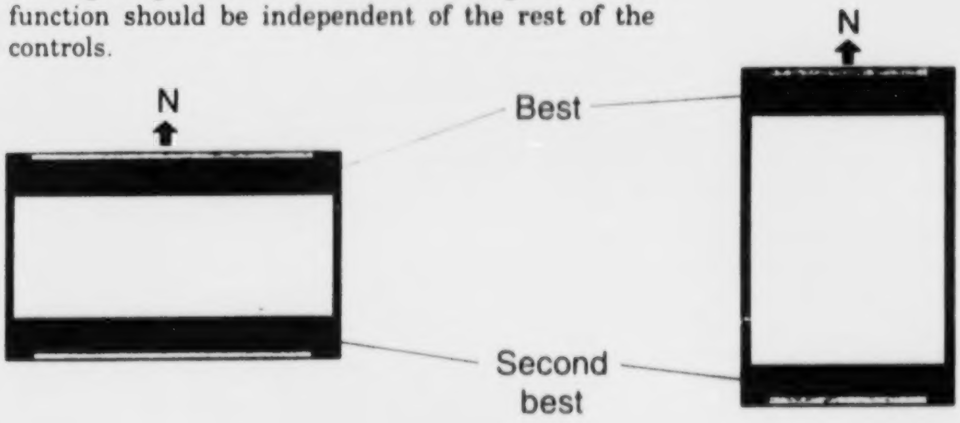
---

1. Designate daylighting zones on north and south perimeters.

   List those spaces which, in terms of quality of environment will benefit most from daylighting. Most school spaces can reap benefits from properly designed daylighting because it can reduce electrical lighting. Moreover, some spaces can be especially enhanced with natural light, such as libraries, art rooms, class-rooms, cafeterias, etc.

Once a list has been established of high priority daylighting spaces, assign those spaces to the north and south perimeters where daylighting opportunities should be best. These will become the daylighting zones. If Non-Optimal Orientation is used for a building, assign those spaces with the highest priority for daylighting to the north and south perimeters and plan to select a superior glazing during *Design Development* for the east- and west-facing windows used for daylighting.

Daylighting zones (Figure 9) refer to an area containing a source of daylight (window, skylight, etc.) in which the lighting system may be dimmed or turned off when daylighting is sufficient. The depth of a daylighting zone will be determined by the size and position of glazing in a space. A day-lighting zone may be only a portion of a larger space, such as a cafeteria or classroom, or it may encompass whole spaces such as offices or break rooms. When a daylighting zone is only a portion of a larger space, the lighting fixture controls servicing the zone function should be independent of the rest of the controls.



Daylighting zones
Optimal orientation

Daylighting zones
Non-optimal orientation

Figure 9. Daylighting zones on the north and south perimeters of buildings offer the bes opportunity for daylighting.

A reasonable daylighting zone can reach 10 to 15 feet into a space, so spaces smaller than that, such as duplicating rooms or small work rooms, do not make full use of the daylighting potential. Be sensitive, as well, to areas where daylighting may be undesirable or only beneficial if strictly controlled, such as projection or darkroom spaces. These spaces will not make best use of daylighting, but can be positioned advantageously by occupying the east and west perimeters where glazing should be minimal.

2. Cluster spaces with similar *annual* occupancy schedules.

Determine which spaces will be used year-round and which will be used only sporadically. Both of these types of spaces produce variances in the HVAC operating schedule for spaces occupied for the length of the regular school year.

Spaces with long operating schedules such as administrative offices, summer school classrooms, athletic facilities, or rooms used for weekend meetings -- may require full conditioning when other spaces are vacant and require only humidity control. Plan for this need by placing these spaces closest to the source of chilled water (Figure 10) or conditioned air. This cuts down on heat gains while the coolant/cooled air is in transit from the chiller or air handler to the point of delivery. Alternatively, give these spaces a separate system. Remember to provide space for mechanical equipment dedicated to one or more spaces that have a variant occupancy schedule.

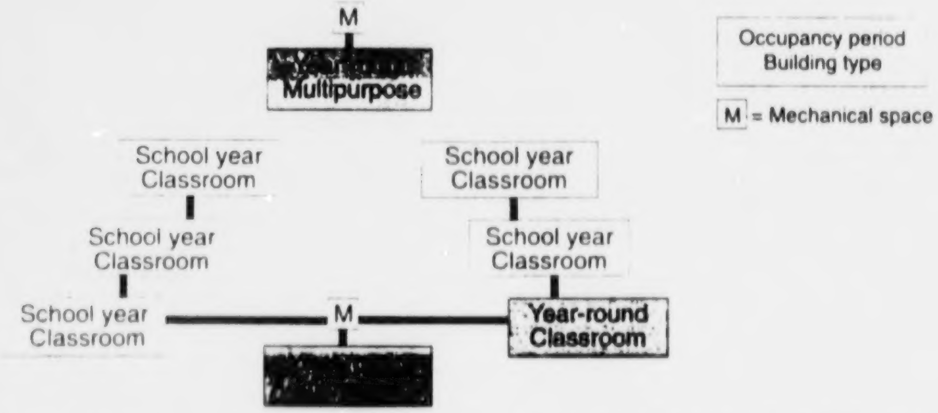

M
Multipurpose
Occupancy period
Building type
M = Mechanical space
School year
Classroom
School year
Classroom
School year
Classroom
School year
Classroom
School year
Classroom
M
Year-round
Classroom

Figure 10. **Buildings/spaces to be used year-round can be located closest to the central mechanical space (Administration and Summer Instruction Classroom Buildings) or alternatively given a separate system (multipurpose building) to reduce heat gains to distribution lines (ducts or chilled water pipes) during the variant occupancy period.**

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If a space with a long occupancy schedule is grouped with spaces that have a comparatively short occupancy schedule, the less occupied spaces may be conditioned unnecessarily at times. While designers can not predict the use of every space in a school, a workable schedule can be drawn from similar schools by considering how the school facility is used when school is not in session and what annual activities occur during the summer or other unoccupied periods of the year.

3. Cluster spaces with similar *daily* occupancy schedules.

Group spaces expected to have the same daily operating schedules into one area and plan to provide, during *System Design*, a means of reducing conditioning and lighting in that area as a whole (i.e., using an energy management system or variable volume distribution) when it is unoccupied. This will help ensure that only the energy required for the actual load is used. Consider providing room for a separate mechanical system to serve spaces with a daily occupancy schedule that varies widely from the rest of the facility (Figure 11). These spaces might include an auditorium used for community assemblies, night school rooms, athletic facilities, and before-and-after school program spaces.

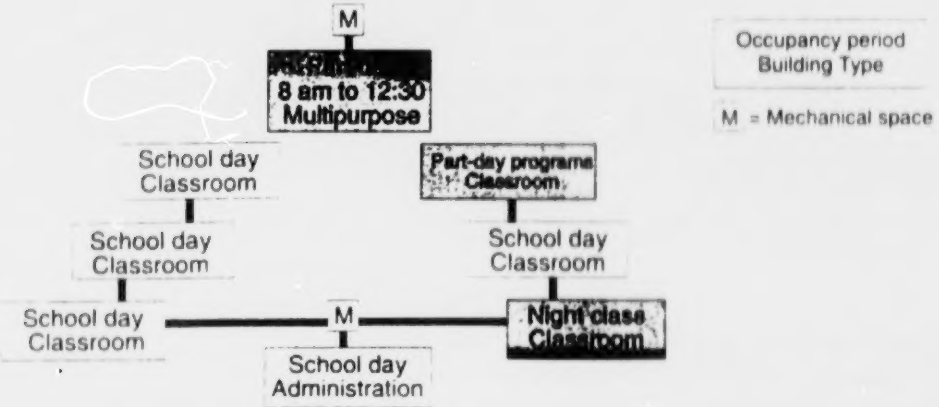
M
8 am to 12:30
Multipurpose
Occupancy period
Building Type
M = Mechanical space
School day
Classroom
Part-day programs
Classroom
School day
Classroom
School day
Classroom
School day
Classroom
M
Night class
Classroom
School day
Administration

Figure 11. Buildings/spaces with daily occupancy schedules differing from the facility in general can be grouped near each other and provided with a separate system.

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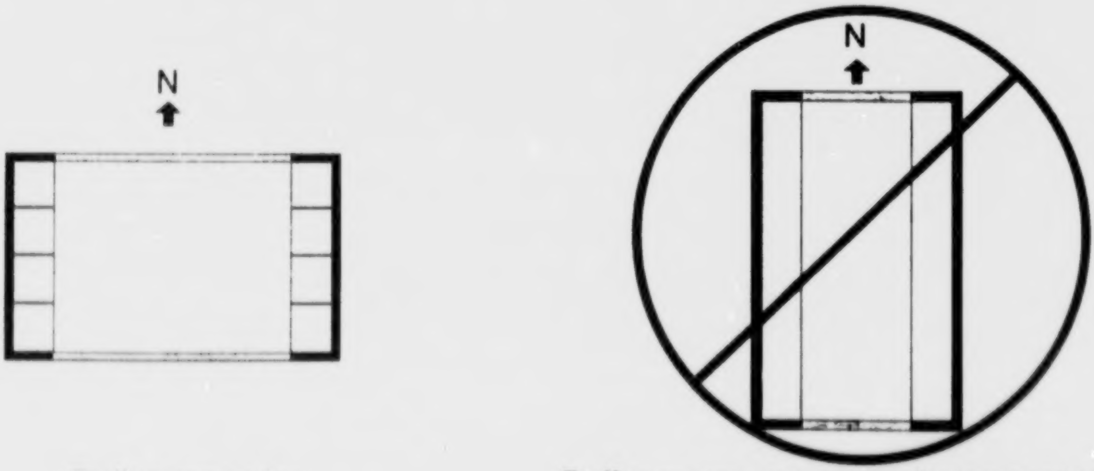
For variable volume or other staged systems locate the central plant or air handler closest to the spaces with longest occupancy schedules, to minimize losses in transit from the point of supply to the point of delivery.

4. Consider buffer zones on the east and west perimeters.

Consider the east and west perimeter spaces as thermal buffer zones. Position spaces on the unglazed spaces of the east and west perimeter that stand to gain little from daylighting, such as those with a short occupancy schedule, limited use, storage cabinets, etc.

Solar radiation absorbed by east- and west-facing exterior walls is conducted through the building envelope and becomes part of the cooling load, so place unconditioned spaces (such as janitorial rooms, staircases, supply closets, outdoor storage, etc.) on the unglazed west and east perimeters to buffer the con-ditioned space (Figure 12). When the absorbed heat is conducted into these buffer zones instead of into conditioned space, the cooling load from solar radiation is diminished.



Buffer zones for Optimal orientation

Buffer zones are generally impractical for Non-optimal orientation

Figure 12. Buffer zones on the east and west perimeters diminish the effect of exterior heat gain. They are generally impractical of the long east and west perimeters of buildings with non-optimal orientation.

Spaces with after school occupancy will also benefit from being positioned on the building's eastern perimeter which will receive no direct sun at that time. Conversely, spaces occupied only in the morning, such as kindergarten classrooms or other part-day program spaces will benefit from locations on the building's west perimeter where they will receive little direct sun during occupied hours.

The effectiveness of buffer zones as an HVAC load reduction option is minimized by the fact that only about 1% (see Figure 5) of the peak HVAC load comes from heat gained from walls. Therefore, implement buffer zones wherever practical and convenient, but do not consider it a major component of an energy conservation plan.

5. Consensus Recommendations

For the design of a low energy facility, the only *Building Configuration* ECM that can be considered as crucial is the designation of daylighting zones. Making this effort will provide a good foundation for a daylighting scheme. Without this planning, a daylighting scheme can require extensive re-design.

If optimal orientation and daylighting zones are not feasible for a given facility, it is advisable to pursue those *strategies* and ECMs not related to daylighting: *Glazing Selection, Enhanced Envelope, Efficient Lighting System Components, Occupancy Sensors,* and *Efficient HVAC Systems.*

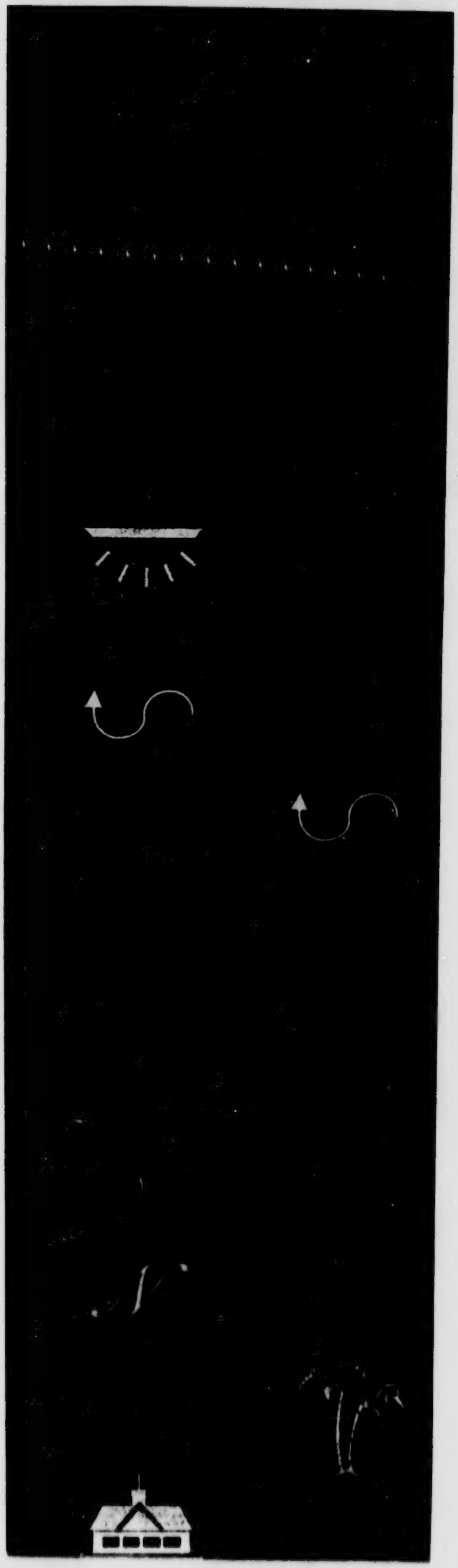
Clustering spaces for advantageous HVAC operation is a good energy design practice idea, however, it is not critical to the development of a low energy building design.

Likewise, buffer zones are a good practice but not an essential part of low energy design. They may be more important in small buildings.

Concentrate during schematic design on properly orienting the building and laying the foundation for daylighting and determining which strategies and ECMs will be incorporated during design development.

Section II

Design Development



During the *Design Development* phase, design teams should focus on three tasks:

1. Select glazing and shading strategies.
2. Solidify daylighting design.
3. Design a heat-rejecting building envelope.

Building on a Good Foundation

During *Schematic Design*, the design team used siting and spatial configuration to lay the foundation of a facility that will minimize solar heat gain and maximize daylighting potential. This supports the goal of targeting HVAC and lighting energy use, the two largest end-uses in Florida educational facilities. During *Design Development*, the design team can build on the daylighting and HVAC reduction schemes by focusing on the building shell: the roof, walls, windows, and exterior shading devices.

Designers should keep in mind that heat gained from the roof and walls of our base case buildings accounted for only 6% of the peak HVAC load. On the other hand, radiant and conductive heat gained through the glazing accounted for 18% of the peak HVAC load. Typical Energy Conservation Measures (ECMs) for roof and walls are discussed in the *Enhanced Envelope* strategy in this section. However, from the energy perspective, design teams should place the most emphasis on fenestration design during *Design Development*. Fenestration ECMs appear in both the Glazing Selection and the Window Shading strategies.

Fenestration refers to the arrangement and design of windows, including the glazing characteristics.

Fenestration Issues

Any discussion of fenestration for schools must consider security and safety issues. Windows are common points of entry for burglars and vandals, expensive to replace and repair, and potentially hazardous areas. For these reasons, non-energy criteria may take priority in fenestration design including glazing type.

If this is the case, choose the supplier whose glazing has the lowest shading coefficient and highest visible transmittance within the type selected.

Fenestration affects energy end-use in a number of ways. First, *infiltration* and *exfiltration* (13% of the HVAC load) of air through spaces between the window frame and the wall affect the pressure balance and temperature of the conditioned space. Second, heat is conducted through the glazing *and* the window frame faster than through the rest of the better insulated wall. Third, heat *radiated* directly from the sun, through the glazing, to surfaces inside the building contributes to the HVAC load (14%). Also, radiated heat absorbed near occupants causes localized areas of overheating increasing the perceived need for cooling and lower thermostat settings Fourth and fifth, the visible portion of solar radiation (light) can satisfy part of the lighting requirement of spaces thereby decreasing both the *heat* produced by the electrical lighting (21% of HVAC load) and the annual *consumption* of the lighting system (25% of the total energy use).

Infiltration **refers to outside air drawn through small passages in the building envelope to the interior.**

Exfiltration **refers to conditioned air being pushed through small passages in the building envelope to the outside.**

These influences on the lighting and HVAC end-uses can be optimized by carefully selecting glazing orientation, glazing type, and glazing shading devices. Designers generally establish glazing orientation during *Schematic Design* by the orientation and shape of the building(s) (see Orientation).

General Fenestration Design Guidelines

- Curb glare and localized overheating by using exterior shading to divert direct-beam sunlight.
- Face glazed areas in educational facilities north and south when possible to provide maximum daylight and maximum shading potential from direct sun. Locate glazing strategically but avoid over glazing.

- Spectrally selective glazings with low shading coefficients, but very high visible transmittance are ideally suited for use with continuously dimming lighting systems.

Glazing Type

Selection of appropriate glazing represents a good opportunity for significant energy savings. Two important issues are pertinent: radiant (as opposed to conductive) heat gain and visible light gain (Figure 13). Ideally, windows would have a minimal thermal penalty *and* assist with lighting requirements. To accomplish this dual role, the infrared or heat portion of solar radiation must be rejected, while the visible or light portion is transmitted. Though both originate from the sun, they are different. In the simplest terms, *visible* solar radiation can be seen, and *infrared* radiation can be felt. By selecting a glazing that rejects a high percentage of radiant heat (a lower shading coefficient or SC), the design team aims for reduced need for cooling energy. By selecting glazing that also transmits a high percentage of visible solar radiation (V_T), the design team targets lighting system energy reduction.

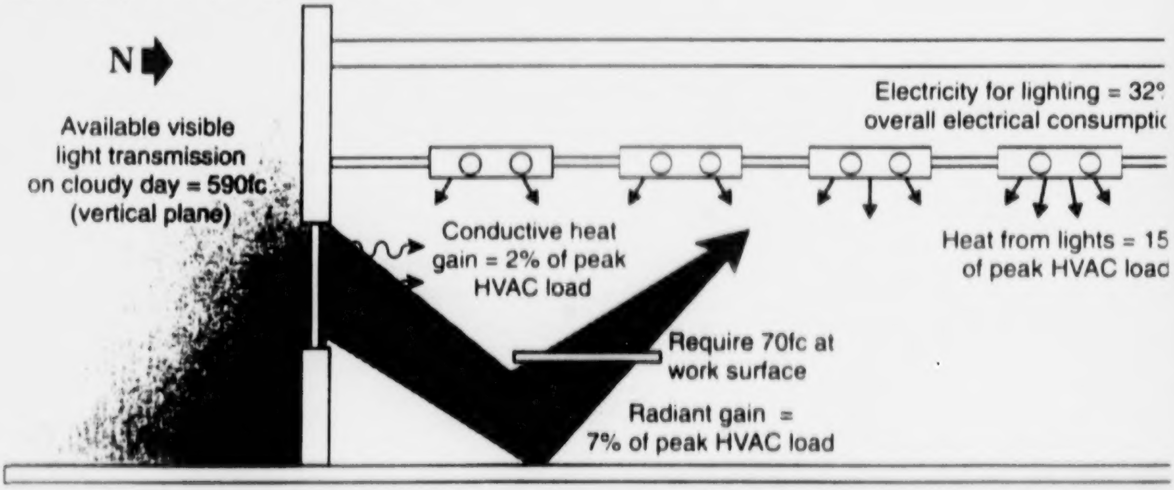

N
Available visible light transmission on cloudy day = 590fc (vertical plane)
Electricity for lighting = 32°
overall electrical consumptic
Conductive heat gain = 2% of peak HVAC load
Heat from lights = 15
of peak HVAC loac
Require 70fc at work surface
Radiant gain = 7% of peak HVAC load

Figure 13. **Glazing provides sunlight in quantities often exceeding required work surfac illumination. Daylighting offers the opportunity to dim lights in the *daylightin* zone (see *Building Configuration*). This is important since, lighting produces abou 15% of the peak HVAC load and constitutes roughly one-third of total educationa facility electrical consumption. Whereas heat gain from windows totals only abou 10% of the peak HVAC load. Window heat gain can be reduced without diminishin the potential lighting savings by using high performance glazing and window shading.**

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Design Development Overview

The *non-dimming* simulations in *Glazing Selection* show the thermal effect of each glazing on the annual HVAC consumption. This represents a scenario where electrical lighting does not automatically respond to available daylighting. The *dimming* (daylighting) simulations assume the presence of the following lighting configuration: F32T-8 lamps, with dimming electronic ballasts and one 15-foot dimming zone. With such a system, electrical lighting automatically res-ponds to available daylight. The daylighting sensor is 15 feet away from the window wall and in the center of the space. These simulations show the effect of each glazing on both lighting *and* HVAC consumption.

Three glazing characteristics commonly referred to are shading coefficients (SC), visible transmission (V_T), and conductivity (U). Shading coefficients are related on a scale of 0-1 as is visible transmittance. Conductivity for glass, like other building materials, is expressed as a U-value (Btu/hr•ft^{2}•°F). The inverse (1÷U-value) of the U-value yields the R-value (ft^{2}•hr•°F/Btu).

For example, the shading coefficient of a single pane of clear glass is 1, the maximum shading coefficient. As this number decreases, the amount of solar radiation admitted by the glazing decreases. Visible light transmission of single-pane clear glazing is 0.9, just under the maximum of 1. As this number is decreased, the amount of visible light transmitted drops. Conductivity, or U-value, of single-pane clear glazing is 1.1 (Btu/hr•ft^{2}•°F). This translates to an R-value of 0.90 (ft^{2}•hr•°F/Btu). As the glass conductance is lowered, the amount of heat conducted through the glass drops. The interaction of these three characteristics determines how well a glazing will perform. The shading coefficient is most important in Florida's climate to thermal performance. Glazing unit conductance is important during the short heating season. Visible limit transmittance is very important to daylighting systems.

Window Shading Devices

Two enemies of daylighting schemes should be addressed during fenestration design: glare and localized overheating (Figure 14). Localized overheating results from solar radiation directly from the sun being absorbed nearby occupants. Direct-beam sunlight can cause more serious thermal discomfort than reflected solar radiation. Glare refers to the brightness of a source of light relative to the other surfaces in the field of vision. Essentially, the eye receives mixed signals. The bright area tells the pupil of the eye to contract while the surrounding darker surfaces tell the pupil to enlarge. Such glare can make visual tasks more difficult.

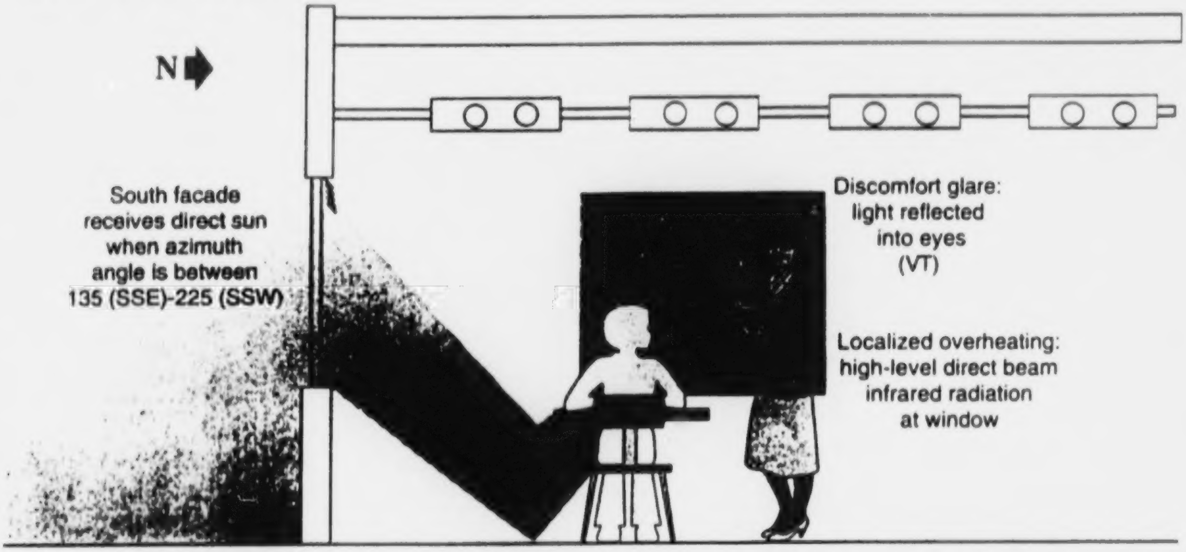
N
South facade receives direct sun when azimuth angle is between 135 (SSE)-225 (SSW)
Discomfort glare: light reflected into eyes (VT)
Localized overheating: high-level direct beam infrared radiation at window

Figure 14. **Daylighting can only work if the visible sunlight is transmitted into the space. When discomfort or distraction occurs because of the heat, glare, noise from the windows, occupants may draw curtains or lower blinds to regain environmental balance. This can seriously detract from the daylighting scheme.**

Glare may be present in varying degrees of intensity and is classified by what effect it has on occupants. Direct-beam sunlight can cause *disability* glare, meaning that an occupant will not be able to perform a given task because of visual disability. Less intense *discomfort* glare can be caused by light reflected off of a work or floor plane into an occupant's eyes. Localized overheating and glare can threaten the success of a daylighting scheme.

Either of these conditions will prompt occupants to cover windows with interior shading devices. Little or no savings will be achieved in a room equipped with a dimming lighting system if the blinds are often closed to block heat or glare arising from direct solar radiation. If the influence of heat gain or glare makes the occupants cover the windows, the daylighting scheme will be of little use and will probably not achieve the desired payback.

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While exterior shading devices perform the traditional role of shielding windows from direct radiant heat gains, such devices have an even more rewarding role. They enable successful daylighting by ensuring that spaces receive diffuse sunlight which contains less infrared radiation and is less likely to produce glare.

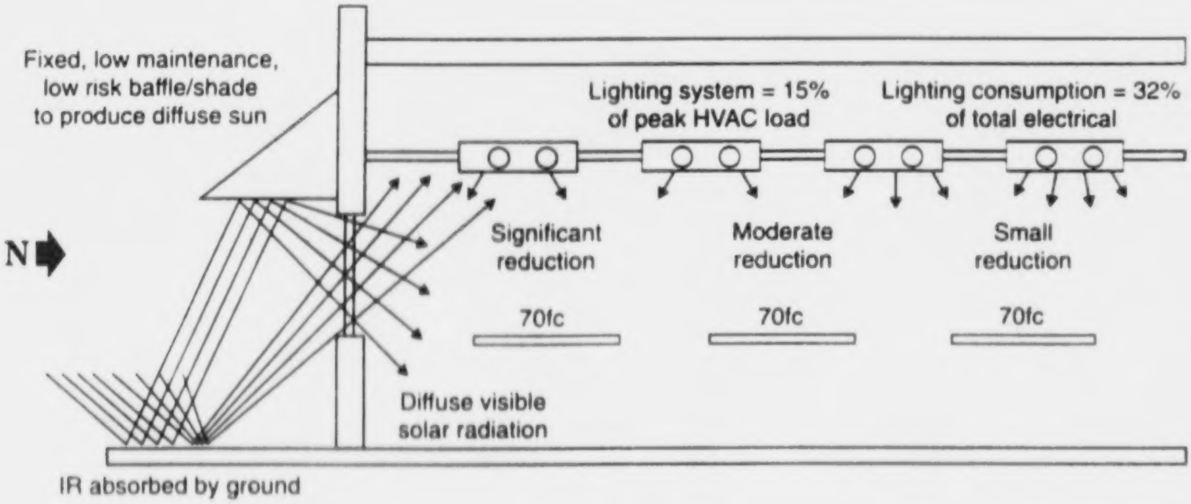
Fixed, low maintenance, low risk baffle/shade to produce diffuse sun
Lighting system = 15% of peak HVAC load
Lighting consumption = 32% of total electrical
N
Significant reduction
Moderate reduction
Small reduction
70fc
70fc
70fc
Diffuse visible solar radiation
IR absorbed by ground

Figure 15. **Window shades play an important role in daylighting. They are most useful on southern facades where sun angles are typically high. The light coming through shaded glazing is diffuse and reflected, similar to light on the north face of the building. Additionally, it contains much less infrared solar radiation than direct sun. Unfortunately, shading east- and west-facing glazing is often difficult and expensive.**

Building Envelope Enhancement

Heat transfer from the opaque building envelope (defined as walls and roof, but not windows) contributes to the air conditioning load, but not as much as internally produced heat. Envelope heat transfer has two major components: conduction and infiltration. The three main strategies for controlling externally gained heat are:

- Stop heat absorption at the exterior surface of the building by using reflective finishes or shading devices.
- Stop the heat transmitted to the interior by using insulation.

- Reduce infiltration by improving the air tightness of the building envelope.[3]

On one hand, envelope measures tend to be conservative and reliable, but they also tend to yield a relatively small reduction (1-4%) in the HVAC load.

Strategies for Design Development

- **Glazing Selection** .... page 39
- Window Shading .... page 47
- Enhanced Envelope .... page 54

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[3] Indoor Air Quality can be affected by infiltration. Infiltration air can carry contaminants and toxins picked up from building materials inside walls and roof, such as particle board or adhesives. Infiltration air can also transports mold spores and various other microscopic organisms from the outside. Furthermore, ventilation and humidity control are essential for maintaining good indoor air quality. The humidity level of infiltration air is extremely difficult to control. Maintaining positive pressure with the building envelope can help to control unwanted air infiltration. Readers may contact the Environmental Protection Agency's Indoor Air Quality (IAQ) Program for more information on indoor air quality. Call the IAQ hotline at 1-800-438-4318.

Design Development Overview

	CLASSROOM BUILDING	Energy Intensity [illegible]	Energy Cost [illegible]	Cooling Capacity Tons	Electric Consumptio kWh	Gas Consumptio Therms	Incremental First Cost $	Energy Cost Savings $	Simple Payback Years
8	Double Pane Clear	44	15495	45	187022	73	5300	-14	-372
11	Single Pane Reflective	43	15092	45	181777	119	6600	389	17
13	Double Pane Reflective	41	14544	42	175242	114	14867	937	16
15	Double Pane Spectrally Selective	40	14123	41	174884	105	9600	1358	7
56	Covered Walkway at h=4'	42	14951	44	184860	106	4400	530	8
57	3.5' Window Shade at h=4'	43	15380	44	185819	104	1925	101	19
58	2' Window Shade at h=4'	43	15450	46	185458	104	1100	31	35
59	2' Lightshelf at h=3.1', T-8, Non-Dimming	43	15422	45	185458	104	1100	59	19
20	Reflective Roof	42	14941	46	180571	110	0	540	0
21	Reflective Wall	43	15389	46	185123	108	0	92	0
22	2' Overhang	43	15442	46	185783	104	5760	39	149
23	4' Overhang	43	15351	45	184590	105	11680	130	90
24	Shade Trees	43	15313	46	184272	120	1600	168	10
25	R-11 Wall	44	15547	46	187242	85	2113	-66	-32
26	R-19 Roof	44	15760	49	187703	75	4599	-279	-16
28	R-30 Roof	43	15240	45	184615	85	4599	241	19

	ADMINISTRATION BUILDING	Energy Intensity kBTU/sqft	Energy Cost $	Cooling Capacity Tons	Electric Consumptio kWh	Gas Consumptio Therms	Incremental First Cost $	Energy Cost Savings $	Simple Payback Years
8	Double Pane Clear	42	9743	24	122997	36	1448	-8	-175
11	Single Pane Reflective	40	9067	23	115061	94	1804	668	3
13	Double Pane Reflective	40	9098	22	116052	50	4063	637	6
15	Double Pane Spectrally Selective	40	9014	22	115111	54	2623	721	4
20	Reflective Roof	41	9300	25	118434	64	0	435	0
21	Reflective Wall	42	9664	25	121854	64	0	71	0
22	2' Overhang	29	9710	25	122368	61	4520	24	185
23	4' Overhang	28	9653	24	121633	61	28160	82	343
24	Shade Trees	42	9564	25	120780	78	1600	171	9
25	R-11 Wall	42	9790	25	123390	42	1652	-55	-30
26	R-19 Roof	43	9908	26	124139	69	3105	-174	-18
28	R-30 Roof	42	9508	24	121071	44	3105	227	14

	ADMINISTRATION BUILDING	Energy Intensity kBTU/sqft	Energy Cost $	Cooling Capacity Tons	Electric Consumptio kWh	Gas Consumptio Therms	Incremental First Cost $	Energy Cost Savings $	Simple Payback Years
8	Double Pane Clear	15.12	3978.94	20	504717	295.93	1068	90	12
11	Single Pane Reflective	15.94	3399.54	17	429048	663.91	1602	669	2
13	Double Pane Reflective	14.56	3245.85	16	419982	511.46	3204	823	4
15	Double Pane Spectrally Selective	14.11	3154.22	16	411902	477.71	2225	914	2
20	Reflective Roof	16.02	3936.9	19	491989	460.13	0	132	0
21	Reflective Wall	16.21	4016.55	20	501831	451.9	0	52	0
22	2' Overhang	16.14	4062.71	20	508280	420.53	8615	6	1457
23	4' Overhang	16.08	4037.24	20	505127	423.7	10320	31	329
24	Shade Trees	16.00	4038.03	18	477952	505.6	1600	31	52
25	R-11 Wall	15.46	4047.34	20	508775	327.4	2868	21	135
26	R-19 Roof	16.31	3878.83	20	484937	522.53	2868	190	15
28	R-30 Roof	15.87	4130.92	20	517202	353.59	4139	-62	-66

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STRATEGY: Glazing Selection

OBJECTIVE: Reject heat from the sun to combat localized overheating and the portion of HVAC load induced by glazing, while providing daylight to reduce the need for electrical lighting.

CONSIDERATIONS: In Florida, glazing selection needs *both* to maximize visible light gains and minimize radiant heat gains. Both sunlight and radiant heat originate from the sun, but the visible and the infrared portions of solar radiation are not the same wavelength. The visible portion of the solar spectrum is light, and the glazing characteristic associated with the admission of light is the *visible transmittance* (V_T). The infrared portion of the solar spectrum is heat, and the glazing characteristic related to the admission of *radiant* heat is the *shading coefficient (SC)*. A third glazing characteristic is rate of heat conduction, *U-value*. Designers should note that a majority of heat gain through windows occurs as *radiant* heat gain (SC) as opposed to conductive heat gain (U). This makes the shading coefficient a more critical design factor than U-values in Florida.

In a brief survey of architects who design educational facilities, no consensus on typical glazing was apparent. Glazings specified for schools in Florida vary widely and are selected to satisfy a range of design needs from security to noise control. All the glazings simulated for this manual are compared to single pane clear glazing, the most basic glazing configuration available.

A desirable glazing for Florida would have a low shading coefficient and high visible transmittance. Avoid glazings with a shading coefficient higher than the visible transmittance. These transmit more heat than light.

No matter how carefully a design team selects glazing as a component of the daylighting scheme, no savings will be achieved if interior lights can not be dimmed or turned off when natural light meets the desired lighting level. Lighting controls and electronic dimming ballasts are discussed in Section III, *System Design*.

ECM OPTIONS:

1. Single-Pane, Clear Glazing
2. Double-Pane, Clear Glazing
3. Reflective and Tinted Glazing
4. Spectrally Selective Glazing
5. Glazing for Overhead Apertures

1. Single-Pane, Clear Glazing

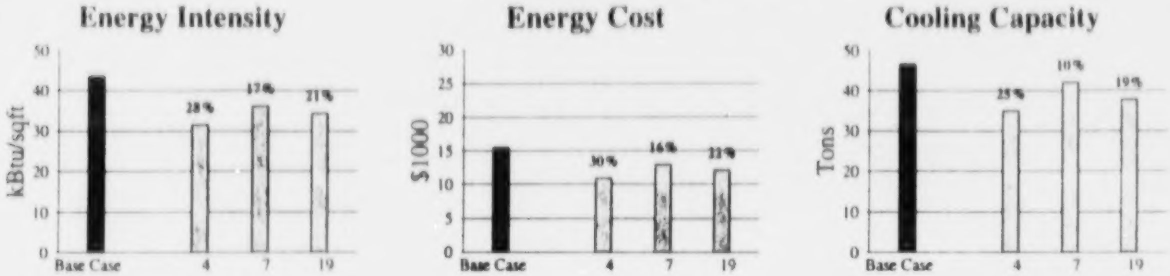
The Base Case Building has clear single-pane glazing and an F34T-12 lighting system with energy-efficient magnetic ballasts. In this configuration, the heat admitted by the glazing was less than the heat generated by the lighting as reported in the simulation output files. If the Base Case Building had no windows (Figure 16) at all, it would use 15-25% less energy. This thermal penalty has led to the construction of many windowless schools in hot climates throughout the country. Contrary to this notion, it is important to recognize that the primary energy-related role of glazing is to provide daylight and that the energy conservation potential afforded by daylighting can exceed the consequent thermal penalty of glazing.

2. Double-Pane Clear Glazing

Double-pane clear glazing has slightly lower visible transmittance, shading coefficient, and thermal conductance than single-pane. This means that the double-pane glazing rejects more heat and slightly more light. Theoretically, double-pane glazing would be expected to save energy in the non-daylighting scenario because it has a higher resistance to conductive heat flow. However, since most of window heat gain is radiative, simulations showed that double-pane clear glazing (Figure 17, #8) had little effect on annual energy consumption.

The explanation centers on one of the unique aspects of cooling and energy use in Florida. Often during spring and autumn months, our schools are air conditioned even when the temperature outside is lower than that maintained inside due to internal sources of heat. During these times, it is actually beneficial to lose additional heat from the building to the outside through higher conductance single-glass. The same situation also occurs frequently during evening hours, even in the summer months, when it is often cooler outside than within the facility, and it becomes beneficial to lose internal heat so that the initial cooling load of the building is lower upon start-up.

CLASSROOM BUILDING



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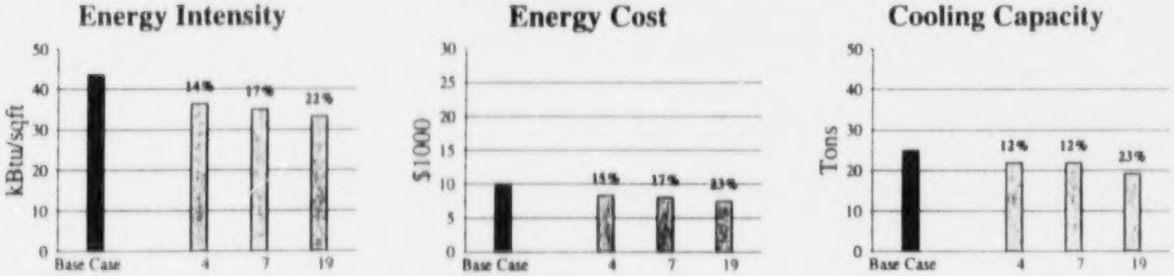
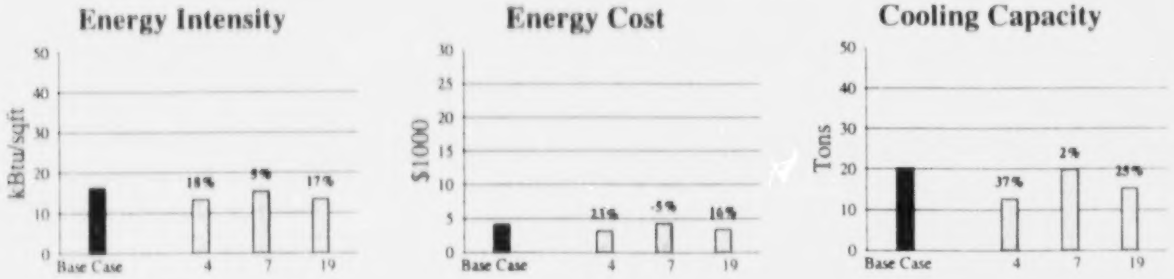


MULTIPURPOSE BUILDING



4	No Windows
7	T-8 Dimming
19	Double Pane Spectrally Selective, T-8 Dimming

Figure 16. Savings from eliminating the thermal penalty associated with glazing (4). Compared to the savings of a daylight responsive (dimming) lighting system (7) and high performance glazing coupled with a dimming system (19).

Double-pane glazing, because of its lower U-value, conducts heat more slowly from the interior to the exterior than single-pane glazing. Consequently, a greater portion of produced internal heat may remain in the building when the HVAC system shifts back into "occupied" mode the following morning.

This phenomenon is emphasized by the ratio of daytime conductive gains through the glazing to internally generated heat. Daytime glazing conduction contributes only about 2% of the HVAC load compared to the heat generated by occupants, lights, and equipment which, totaled, accounts for more than 50% of the peak HVAC load. This implies that the important role of glazing in Florida is to prevent excessive solar gains. Lower conductance from the north glazing is of minor importance. This contradicts conventional wisdom from northern climates which says that glazing should primarily prevent conduction.

3. Reflective and Tinted Glazing

The shading coefficient and visible transmission characteristics of clear glass can be altered by applying films or coatings after the glass is produced. Glazing can also be incorporated by adding various metals or minerals during production. These treatments affect the way the solar radiation is transmitted by the glazing. A wide variety effects can be achieved to serve a differing of climates. The glazing industry offers an impressive array of reflective and tinted glazings designed for superior performance.

For Florida, these treatments offer the capability of manipulating the ratio of radiant heat to visible light transmission. Manufacturer's data should be reviewed carefully to determine a glazing's appropriateness for Florida. Select a window glazing with a low shading coefficient (SC) and high visible transmittance (V_T).

This type of glazing supports the HVAC objectives for radiant heat gain reduction and the lighting objectives by admitting visible light for daylighting. Again, avoid glazing products whose shading coefficient is higher than visible transmittance (meaning more heat is admitted than light).

Compared to single-pane clear glazing (Base Case), the single-pane reflective glazing (Figure 17, #11) was reduced energy use. Also, the double-pane reflective glazing (Figure 17, #13) saved more energy than double-pane clear (Figure 17, #8) glazing. Thus, as with clear glazing, the single-pane reflective glazing is superior to the double-pane reflective glazing. Again, this is contrary to conventional wisdom (see discussion at *Double-Pane Clear Glazing*).

4. Spectrally Selective Glazing

Until recently, reflective and tinted glazings (Figure 17, #11 & #15) have offered the only means of manipulating the ratio of radiant heat transmission to visible light transmission. However, a new class of glazing has recently become available that is tailor-made for daylighting applications in Florida: spectrally selective glazing.

Spectrally selective means that a glazing *selects* only certain portions of the *solar spect*rum for transmission. Spectrally selective glazing offers the advantage of *maximizing* the visible solar radiation transmission while reducing the admitted infrared solar radiation.

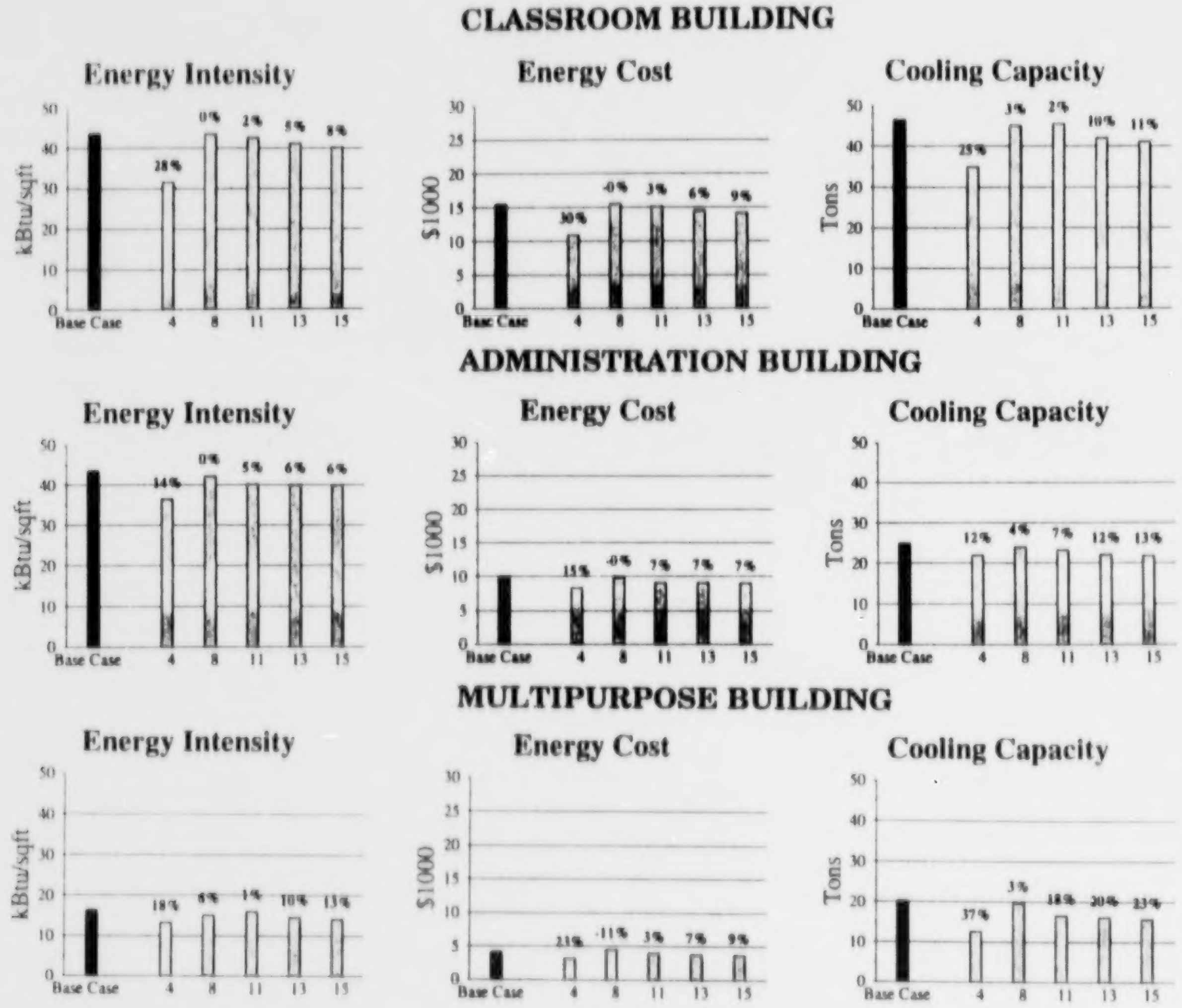
Reflective and tinted glazing minimizes heat transmission without deliberate regard for visible transmission. Unfortunately, some glazing literature advertises spectral selectivity without clarifying whether it is appropriate for a cooling or heating dominated climate. Some products advertised as *spectrally selective* glazings actually let in more heat than light. Therefore, designers should review the actual specifications of the glazing and use the simple procedure outlined here to verify the appro-priateness of a glazing for Florida.

Verifying spectral selectivity - The light-to-solar gain (LSG) equation offers a simple verification of spectral selectivity. The LSG equation calls for the visible transmittance (T_v) and the shading coefficient (S_c) of the glazing (both of these numbers are available from the manuafacturer):

$$LSG = \frac{T_v}{S_c}$$

When LSG=1, the same amount of visible light and radiant heat are transmitted by the glazing. For daylighting applications in Florida, select glazings with LSG higher than 1.

The spectrally selective glazing (Figure 17, #13) outperforned the single-pane reflective glass (Figure 17, #11) even though it is an insulated unit. This type of glazing coupled with T-8, electronic dimming ballast lighting



4	No Windows
8	Double Pane Clear
11	Single Pane Reflective
13	Double Pane Reflective
15	Double Pane Spectrally Selective

Figure 17. **Double pane spectrally selective glazing (15) combines a very low shading coefficient with high visible transmittance making them a superior choice over double pane reflective for daylit spaces. The "No Windows" scenario is presented here to show the maximum potential savings from eliminating the conductive and radiant heat gain form windows; NOT to suggest that a windowless environment would be desirable or acceptable.**

configuration (Figure 18, #19) provides very high energy and cost savings. It also strongly combats localized overheating. This represents one of the highest energy-efficiency combinations simulated, mitigating solar heat gains while reducing the energy consumption associated with artifical lighting. However, glare can still be a threat to successful daylighting if not addressed.

5. Glazing for Overhead Apertures

Skylights, roof monitors, light boxes, and other glazed roof apertures may be used occasionally to create a dramatic entry or gathering space. In general, these features can save energy if properly designed. However, they have a reputation as maintenance problems. This, coupled with relatively modest savings even with high performance glazing, makes them a high-risk, low-reward ECM for classroom buildings.

When using this type of architectural feature (such as roof monitors), opt for a design that allows for north-facing glazing. Avoid east- and west-facing glazing.

6. Consensus Recommendations

For daylighting applicatons, select a single-pane reflective glazing whose visible transmittance is greater than its shading coefficient or a spectrally selective glazing (typically very high visible transmittance).

For any east- and west-facing glazing, select a glazing with a shading coefficient of 0.5 or lower.

If low shading coefficient glazing is not selected for east, west and south exposures, plan for exterior shading from shading devices, building elements or shade trees (see *Window Shading*).

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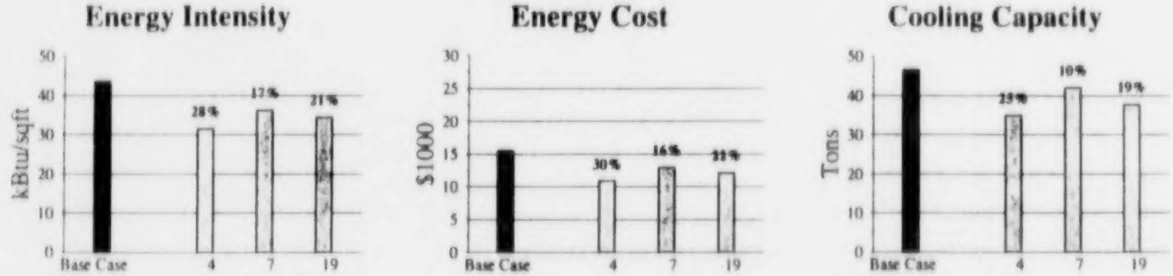

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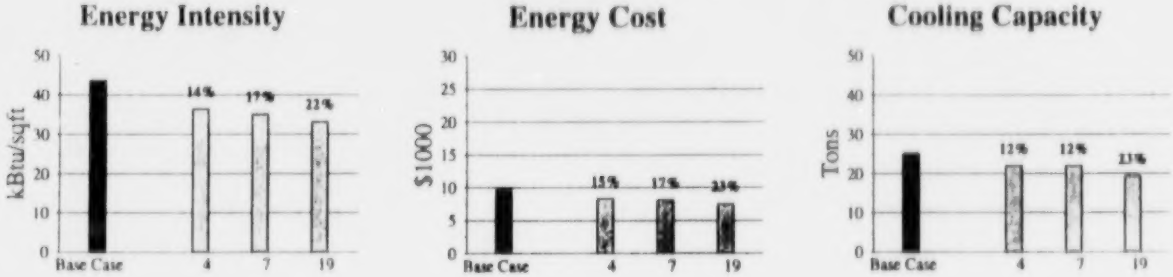
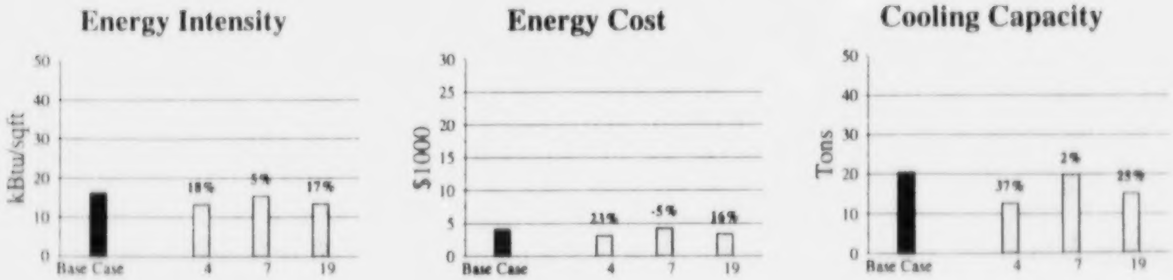


MULTIPURPOSE BUILDING



4	No Windows
7	T-8 Dimming
19	Double Pane Spectrally Selective, T-8 Dimming

Figure 18. Spectrally selective glazing coupled with T-8 lamps and continuously dimming electronic ballasts almost overcomes the thermal penalty associated with glazing, approaching the energy consumption level of the "no windows" scenario.

STRATEGY: Window Shading

OBJECTIVE: Block *direct beam* solar radiation to reduce heat gain, glare, and localized overheating.

CONSIDERATIONS: Technically, window shading can be accomplished with interior and exterior elements. Exterior elements are preferable because they do a superior job of extracting the heat from solar radiation. A window shading plane, or element, serves one main purpose: to stop sun from shining directly on and/or through a window. Sunlight entering the glazing will be diffuse and reflected, more similar to sunlight from the northern exposure. This diffuse and reflected light is preferable to direct-beam sunlight because it reduces radiant heat gain, localized overheating, and glare. While a high performance glazing such as single-pane reflective or spectrally selective glazing can accomplish the first two of these, it can not deter glare. The success of a daylighting strategy thereby increases significantly.

Direct radiation focuses intense light and heat in a relatively small area. This can cause thermal discomfort and prompt occupants to close interior blinds. Likewise, when sunlight projects directly into an occupant's eyes, or reflects off of a work surface into the eyes, the resulting dis-comfort glare induces occupants to close blinds.

It is also important to be aware that horizontal window shades may provide unauthorized individuals access to the roof. Additionally, window shaues may pose a safety threat if extremely high winds blow them away from the building. These are serious issues that should be discussed thoroughly.

ECM OPTIONS:

1. Interior window shading
2. Horizontal window shading on south facade
3. Light shelves
4. Consensus Recommendations

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1. Interior Shading Devices

   When glare and localized overheating occur, occupants will act to change these uncomfortable

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conditions using interior shading devices if they are available. But using interior blinds as sun control devices can defeat daylighting plans. First, shades stop a large portion of the natural light from contributing to the daylighting scheme. Second, they do not stop radiant heat transfer. When the blinds are closed, the heat from the sun still passes through the window, and much is absorbed by the shades, and becomes a part of the HVAC load. A varying portion is reradiated back through the glazing to surfaces outside.

Extensive use of interior window shades means that a space will still receive most of the incident radiant heat while not enjoying the full daylighting benefit. Ideally, interior shading devices are used to darken rooms for projection activities, not as glare or heat gain reducers.

The amount of heat absorbed by the shade depends on its absorptance; the amount reradiated (given up as radiant energy, back through the glazing, to the night sky) depends on its *emissivity*. The desirable material for interior shading devices would be a bright, white, smooth material with a low absorptance and a high emissivity, meaning that it would absorb a small portion of heat and would readily give up its absorbed heat once the outside sky conditions permitted reradiation.

2. Horizontal Window Shading on South Facade

Again, window shading serves one main purpose: to stop sun from shining directly on and/or through a window and to mitigate the effect of glare and localized overheating. While they do save some energy intrinsically (Figure 23), the greater role of window shading is to provide quality daylighting so that electrical lighting may be reduced.

With proper window shading, sunlight entering south-facing glazing will be diffuse and reflected, and more similar to light from northern windows. This diffuse and reflected sunshine is preferable to direct-beam sunshine because direct beam sun causes localized overheating and glare, two factors that can short curcuit daylighting strategies (Figure 20).

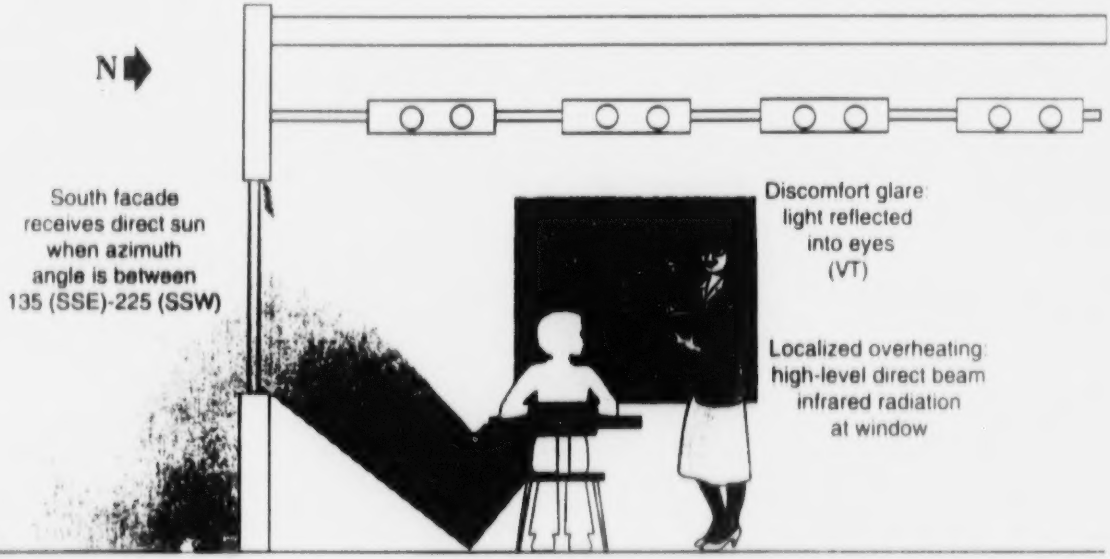

N
South facade receives direct sun when azimuth angle is between 135 (SSE)-225 (SSW)
Discomfort glare: light reflected into eyes (VT)
Localized overheating: high-level direct beam infrared radiation at window

Figure 20. **Localized overheating, refers to "hot spots" where direct beam heat (infrared radiation) is absorbed by occupants. Glare refers to "bright spots" in the occupants' field of vision.**

Glare: Glare will be easier to prevent once its definition is clear.

> *Glare occurs when one area of the visual field is much brighter than the rest; it is a function of the difference in the light level at the bright spot (usually a window or unshielded electric light) and the rest of the visual field.*

The worst glare, *disability glare*, occurs when direct-beam sunlight shines into a person's eyes or reflects off a bright surface (Figure 13). This problem occurs more commonly with sun coming through east-, west-, and south-facing windows. North-facing windows admit mostly diffuse or reflected sunshine which can still be a source of glare if the area surrounding the window is comparatively dark. Glare can be alleviated by eliminating direct-beam sunlight with exterior shades and by specifying a light-colored interior wall finish that will not be in high contrast to the bright window.

Although seeming contradictory, glare from windows generally decreases as the size of the aperture relative to the wall increases. This is because the window will be a larger portion of the field of vision. More light will come in, increasing illumination of surrounding surfaces; therefore, the difference in light level of the illumination source and the surroundings will decrease.

While specialty glazings would seem to address this problem, a closer look reveals a flaw in this line of thinking. They act to reduce the visible light transmission and therefore the natural light level; however, the difference in the two light levels will remain roughly the same. The glare issue will remain unsolved unless shading devices are provided.

Localized Overheating: Localized overheating, an equally irritating condition, occurs when occupants are seated or working near a window that is absorbing radiation from the sun (Figure 13). When direct sunlight (or heat from any other source) is focused in one particular spot, seating in that area may become intolerable. Occupants may move away from the zone or may again block the glazing with interior shading. Glazing with a low shading coefficient can diminish the effect of localized overheating by reducing the transmission of near infrared radiation; however, glazing with shading coefficients lower than clear glass also have visible transmittance lower than glass. Refer to *Glazing Selection* for more information on the desirable combination of characteristics.

Radiant Heat Gain: As discussed under Double-Pane Clear Glazing, radiant solar heat gains account for roughly 7% of the peak HVAC load compared to the conductive heat contribution of 2% (Figure 13). The best way to eliminate radiant heat gain to the glazing is to block the path between the sun and glazing. This can be accomplished with a glazing treatment as previously detailed or with an exterior shading element.

Forms of Shading: Horizontal window shades come in a variety of forms such as overhangs (Figure 21) and can be a major component of an elevation's composition. In general, any architectural element

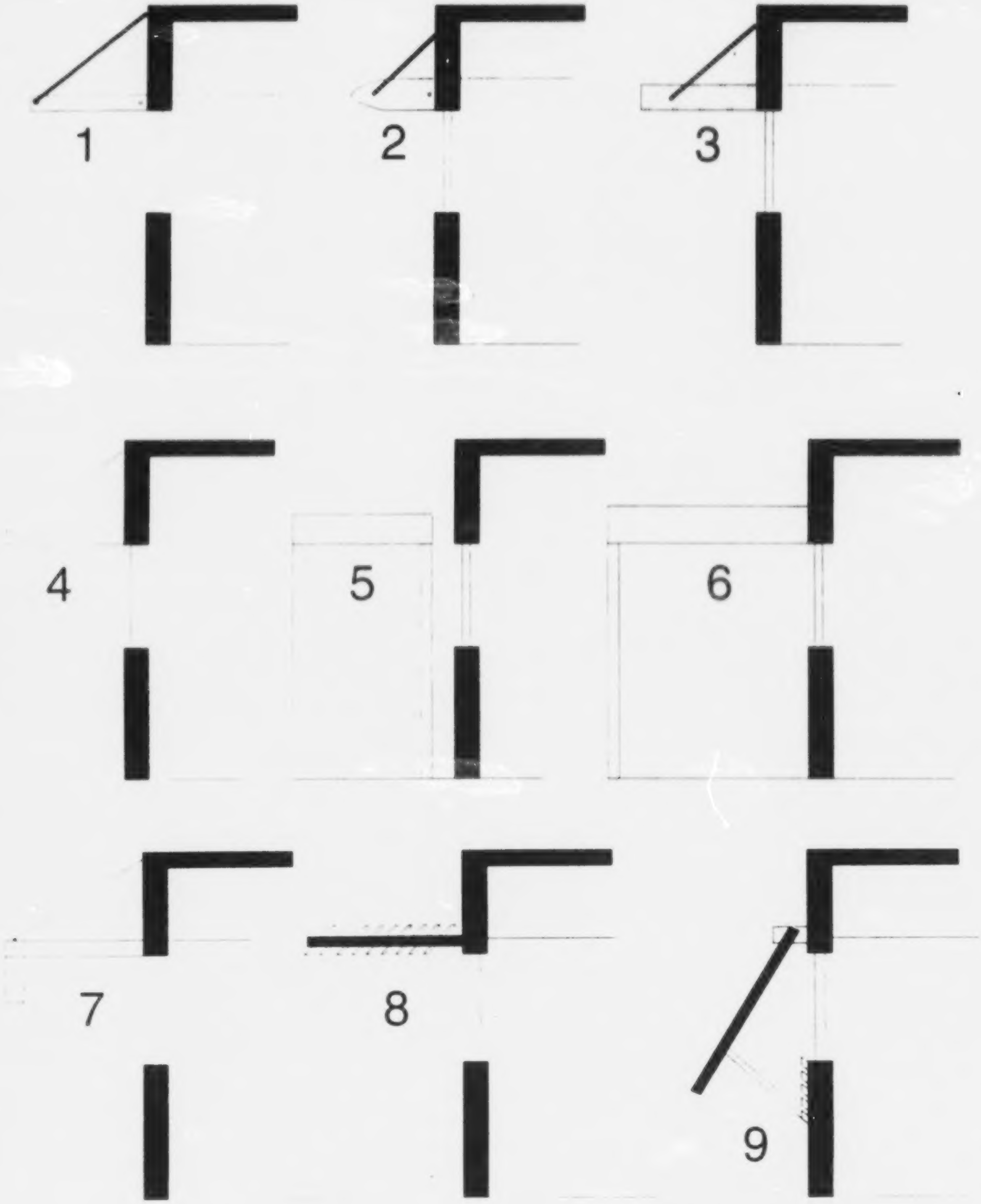


Figure 21. Common forms of window shading.

that intercepts solar radiation before it reaches the glazing functions as a window shading plane. Shading techniques work best on south-facing glazing because the sunlight originates from relatively high angles in the sky; whereas, east- and west-facing glazing receives sun from angles closer to the horizon.

Recommendations in the *Schematic Design* section discourage east- and west-facing glazing because sunshine from these directions is difficult to control. Vertical window shading can be used to shade this glazing; however, it will block the view from the window at least partially. Interior blinds are likely to be essential for spaces with east- and west-facing glazing to ensure the comfort of occupants since glare and localized over-heating will be prevalent.

Window shades that double as hurricane shutters provide very effective shading; however, they may be targets for vandalism and should be incorporated with caution. As with any type of removable device, the shading strategy will be destroyed if the device is removed and not replaced.

Covered walkways (Figure 23, #56) can provide window shading. A few precautions should be considered because the covering may be so wide (6 ft.) that windows seen darkened. The walkway surface should be a light-colored, reflective surface such as floated concrete, painted white so that *sunlight* will be reflected up into the glazing rather than absorbed by the wide walkway (Figure ??). Also, traffic on the walkway may distract students causing the instructor to close the blinds. This is undesirable and can adversely affect planned daylighting.

Sizing: The important variables in horizontal shading plane design are the *lowest* undesirable sun angle (same as the highest desirable sun angle) and the vertical position of the shading plane relative to the bottom of the window. Using these parameters, figure the length of the shading device using the following equation to provide full shading (refer also to Figure 22).

$$l = h * \tan(90\text{-}a)$$

where,

l = length of the window shade
h = vertical position of the window shade, measured from the bottom of the window
a = lowest undesirable sun altitude angle

For example, if h = 45" and a = 42°,

l = 45" * tan(90-42)
l = 45" * tan48
l = 45" * 1.11
l = 49.95"
l = 4'2"

A horizontal window shade could be shaped like an awning, and in that case l in formula above would refer a the line drawn from the lowest point of the sloped plane perpendicular to the face of the building.

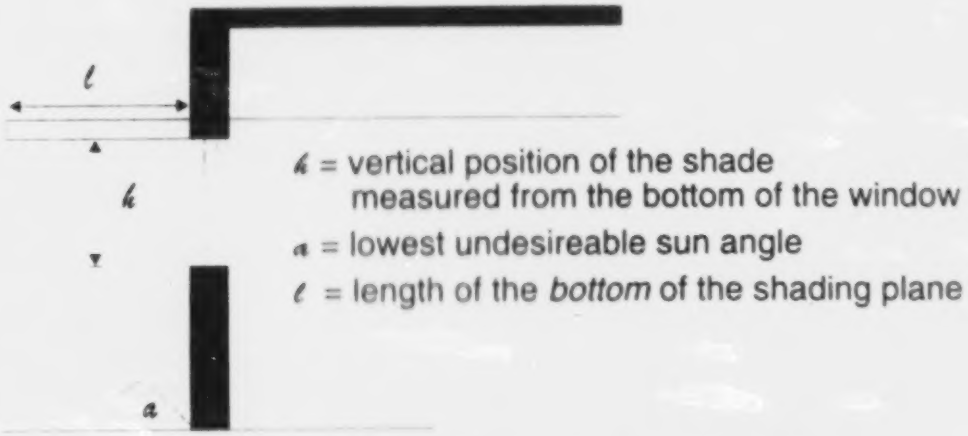
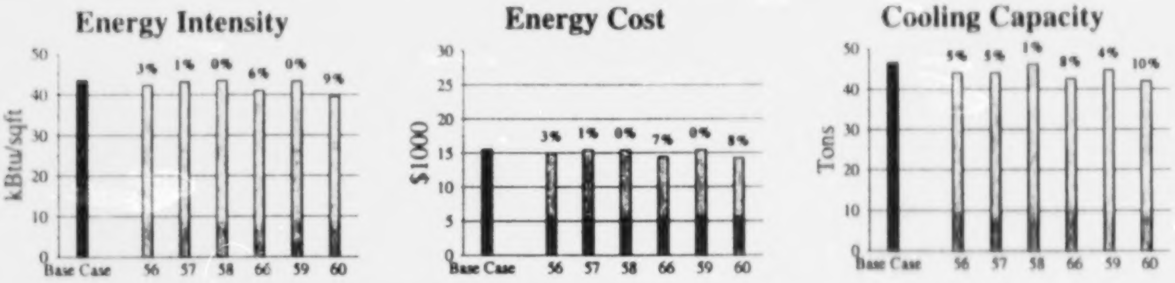

l
h
a
h = vertical position of the shade measured from the bottom of the window
a = lowest undesireable sun angle
l = length of the *bottom* of the shading plane

Figure 22. Variables in designing window shading.

3. Light Shelves

One type of window shade can significantly enhance daylighting. A light shelf is a horizontal, opaque plane the same width as a window, or group of windows. Rather than being positioned at the top of the window, it is positioned roughly one-third of the window height below the top of the window (this alters the "h" value in the sizing equation). It shades the lower portion of the window and reflects sun through the top of the window onto the ceiling plane. This serves two purposes. First, daylight reflected off the ceiling plane is projected further into the space (compared to direct-beam sunlight) making a more even distribution of light; and second, localized overheating and glare are reduced because most of the direct sun has been obstructed.

CLASSROOM BUILDING



56	Covered Walkway at h=4'
57	3.5' Window Shade at h=4'
58	2' Window Shade at h=4'
66	3.5 Window Shade at h=3.1', Single Pane Reflective Glazing
59	2' Lightshelf at h=3.1', T-8, Non-Dimming
60	2' Light shelf at h=3.1', T-8, Dimming

Figure 23. **Window shade can be used to reduce energy consumption however, their greater contribution is as an enabler for daylighting because they can reduce the occurrence of localized overheating and discomfort glare.**

5. Consensus Recommendations

Provide exterior window shading to minimize the need for interior blinds and associated reductions in available daylight. Where interior blinds are provided, use light colored materials.

Properly size horizontal window shades and provide them on the south side of the building to prevent glare and localized overheating.

Consider light shelves on south windows for daylighting applications to project light into the building interior while blocking direct solar onto areas adjacent to the glazing.

Use horizontal and vertical shades for any large areas of east and west glazing.

STRATEGY: Enhanced Envelope

OBJECTIVE: Reduce solar heat gains from roof and walls.

Note: Glazing has heat transfer characteristics that differ from the opaque portions of the building envelope and are covered under *Glazing Selection* in this section.

CONSIDERATIONS: Exterior surfaces either reflect or absorb heat from the sun. The materials of the wall or roof assembly conduct absorbed heat to interior spaces, where it becomes part of the air conditioning load. Exterior finishes that have high reflectivity (70% or higher) and wall shading devices reduce the amount of solar radiation gained and produce small reductions in the HVAC load.

When considering the opaque envelope target the roof for reflective finishes. The roof receives sun for most of the day and makes up a larger portion of the peak HVAC load (~5%). Heat gain from solar radiation collected by walls in a code- insulated facility represents a small portion (~2%) of the peak HVAC load. This reemphasizes the point that schools are internally load-dominated and that ECMs aimed at external loads, or heat gains, will not produce reductions as dramatic as ECMs which target internally generated heat.

Wall and roof insulation slows the conduction of absorbed heat from the exterior surface to the interior. This measure may produce small savings, but simulations indicate that increased insulation may actually cause HVAC loads to increase slightly as it traps internally generated heat inside, slowing its conduction out of the building during the evening hours and swing seasons when the temperature outside is lower than its thermostat set-point.

ECM OPTIONS:

1. Reflective Exterior Finishes
2. Wall Shading
3. Insulation
4. Consensus Recommendations

1. Reflective exterior finishes

Over half of the opaque-envelope heat gain occurs at the roof plane (4%); the roof is in the sun all day and, unless it is sloped, its orientation is irrelevant. It always receives direct sun except just after sunrise and just before sunset. Walls, on the other hand, receive direct sun for only the part of the day they are facing the sun. For these reasons, wall reflectance has less effect on the overall HVAC consumption than roof reflectance (Figure 24).

Two main characteristics are important when selecting a reflective roof finish: the reflectivity and the emissivity. Reflectivity, being the more familiar measure, can give a good indication of how well a roof finish will perform. Generally speaking, strive for a reflectivity of 65% or more.

The other measure, emissivity, refers to a material's ability to radiate absorbed heat. The lower its emissivity, the less able a material is to radiate heat absorbed from the sun during the day. Ideally, a roof finish would reflect 70-80% of incident solar radiation, and then would radiate to the night sky most of the heat it does absorb.

If a material can not radiate the heat it has absorbed, it will conduct the heat to the roof deck, which will radiate it to the interior surface of the building for as long as the interior temperatures are lower than the temperature of the roof deck. Select a roof finish that can both reflect the sun's radiation and reradiate the heat it has absorbed (see following table). This can generally be achieved by white finishes: e.g., white single ply membranes, or white metal roofing. The solar reflectivity and emissivity of common building materials are available from a variety of engineering design handbooks. Specific material properties may be available from manufacturers.

While exterior finishes will not always be chosen on the basis of energy efficiency, a reflective option may be available in whatever system has been selected. Metal, concrete tile, concrete "shingle", aluminum shingle roof, and single-ply roofing sys-tems are all available in a reflective color (white), usually at no additional cost.

The following table of reflectivity values of currently available roofing materials may aid design teams in selecting roof finishes. The values were measured by the Desert Solar Energy Testing (DSET) Laboratory. The overall solar reflectivity is the index designers should use to select reflective finishes.

SOLAR REFLECTANCE OF TYPICAL ROOFING MATERIALS

Specimen	Reflectance			
	Solar	Ultraviolet	Visible	Near Infrared
Aluminum	**60.9**	29.3	49.4	73.5
Black Single Ply	**6.2**	6.7	6.4	6.0
Gray Single Ply	**23.1**	13.5	27.2	20.2
White Single Ply	**68.7**	16.7	68.3	75.0
Smooth Bitumen	**5.8**	4.2	5.2	6.6
Black Shingles	**5.0**	4.6	5.3	4.8
White Fiberglass Shingles	**25.3**	9.9	27.0	25.2
Asphalt Shingle with elastomeric coating	**71.4**	16.7	80.0	69.1
White fiber cement roofing shingle	**76.6**	18.1	85.9	74.0
Painted white metal roofing	**66.6**	18.2	73.2	65.4
Red cement tile	**17.6**	7.0	13.1	23.1
White concrete tile (barrel)	**72.8**	22.0	77.7	73.4

Source: Parker, et.al., 1993. Laboratory Testing of Reflectance Properties of Roofing Materials, FSEC-CR-670-93, Florida Solar Energy Center, Cape Canaveral, FL.

Materials research currently being conducted on *spectrally selective* finishes at Lawrence Berkeley Laboratory explores the idea of engineering the characteristics of materials to reflect the infrared portion of the spectrum but not the visible. Designers could choose an aesthetically pleasing color, green for example, that would have the same infrared reflectance as a white-colored surface. This technology was originally used by the U.S. Navy, but is not commercially available. Once developed, these materials

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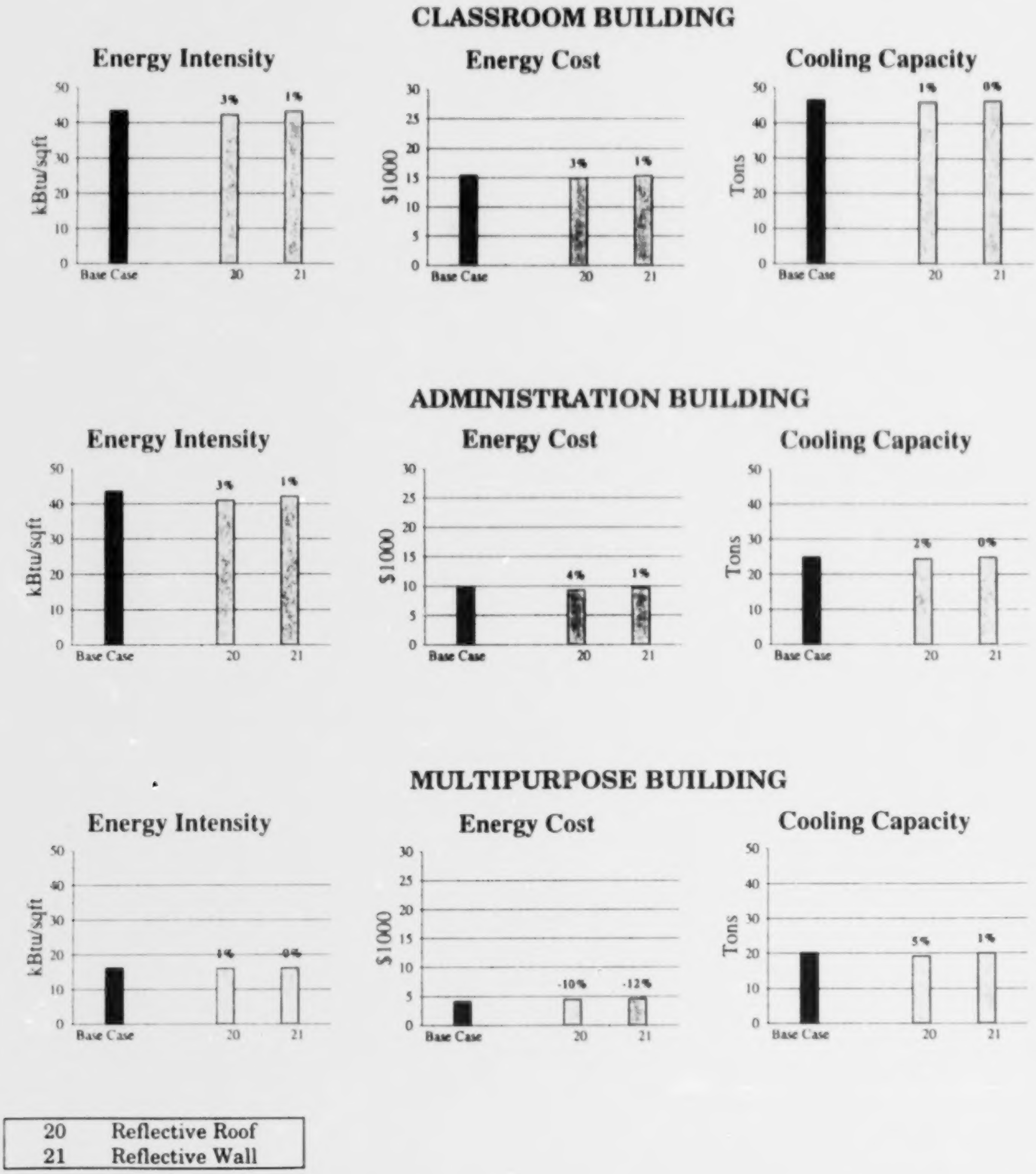


Figure 24. Reflective exterior finishes reduce energy consumption by 2-3% similar to the change seen with non-optimal orientation. This further illustrates that a relatively small portion of the HVAC load comes from solar gains.

could provide designers with additional color options while preserving thermal performance.

2. Wall Shading

Two different types of wall shading were simulated for this study: roof overhangs and a canopy of mature shade trees.

Roof overhangs (Figure 26, #22 & #23) are commonly considered energy savers because they block solar radiation from reaching part of the wall. Two sizes of overhangs were simulated: two feet on all sides and four feet on all sides. However, neither decreased energy use significantly. This is not surprising since heat conducted by the wall contributes only about 1% of the peak HVAC load.

If overhangs could be designed to shade glazing, that would change the effectiveness of this ECM considerably. Often, this is impractical because the length of the overhang (away from the facade) can be costly. For example, using the sizing method given for window shading (Figure 22), if the roof line were 2 feet above the top of a 4 foot window (h=4'+2'=6') and only sun below the altitude angle of 42° (a=48) were desired, the length (l) of the overhang to provide full shading would need to be:

$$l/h = \tan(90\text{-}a)$$
$$l/6 = \tan(90\text{-}42)$$
$$l = 6(1.11)$$
$$l = 6.66'$$

One way to make short overhangs more effective is to reduce the separation between the roof line and window height.

Against the greater cost of overhangs, however, must be balanced the ability to control glare and localized overheating, which may be important to daylighting strategies where no other window shading is available (see Window Shading).

Shade trees (Figures 25 & 26, #24) are a longterm investment with some risk of failure and high maintenance; however, they are beautiful and, when mature, can make a small contribution to an air conditioning reduction strategy. Our simulations indicated a 1.3% energy savings produced from mature trees. The energy savings is primarily due to shading of glass. So if investing in landscaping is part of the base design, select trees that, when mature, will shade the south, east, and west facades; but do not rely on this as the only means of providing shading for exposed glass. If window shading is part of a daylighting scheme, more immediately effective methods of shading should be employed.

Native trees, such as live oaks, require less maintenance and have a greater chance of surviving to maturity. Evergreen varieties offer shade throughout the winter, which is desirable for Central and Southern Florida but may not be for North Florida. Plant trees so that the *mature* branch spread is far enough away from the building to prevent unauthorized persons from using them as a ladder to the roof (Figure 25).

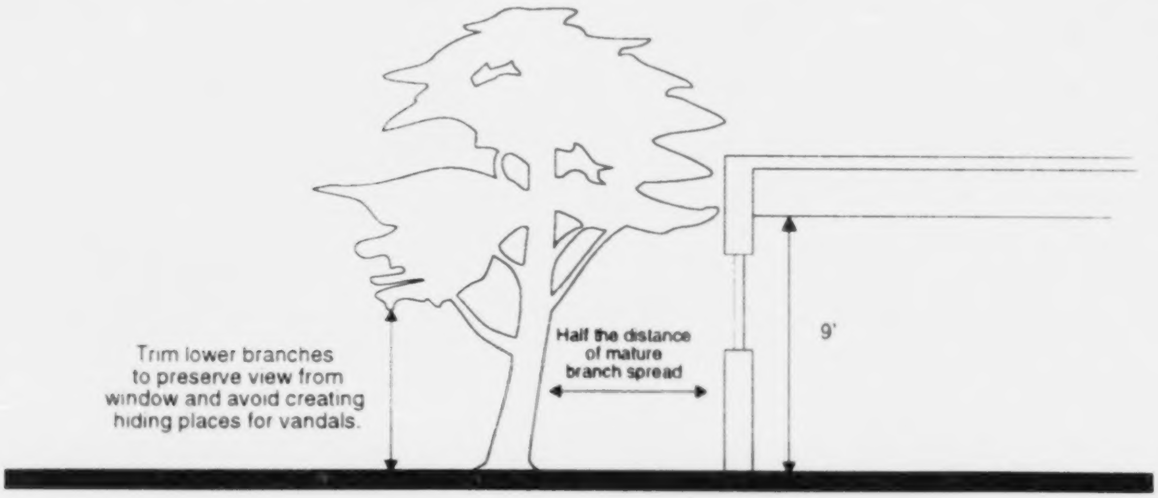
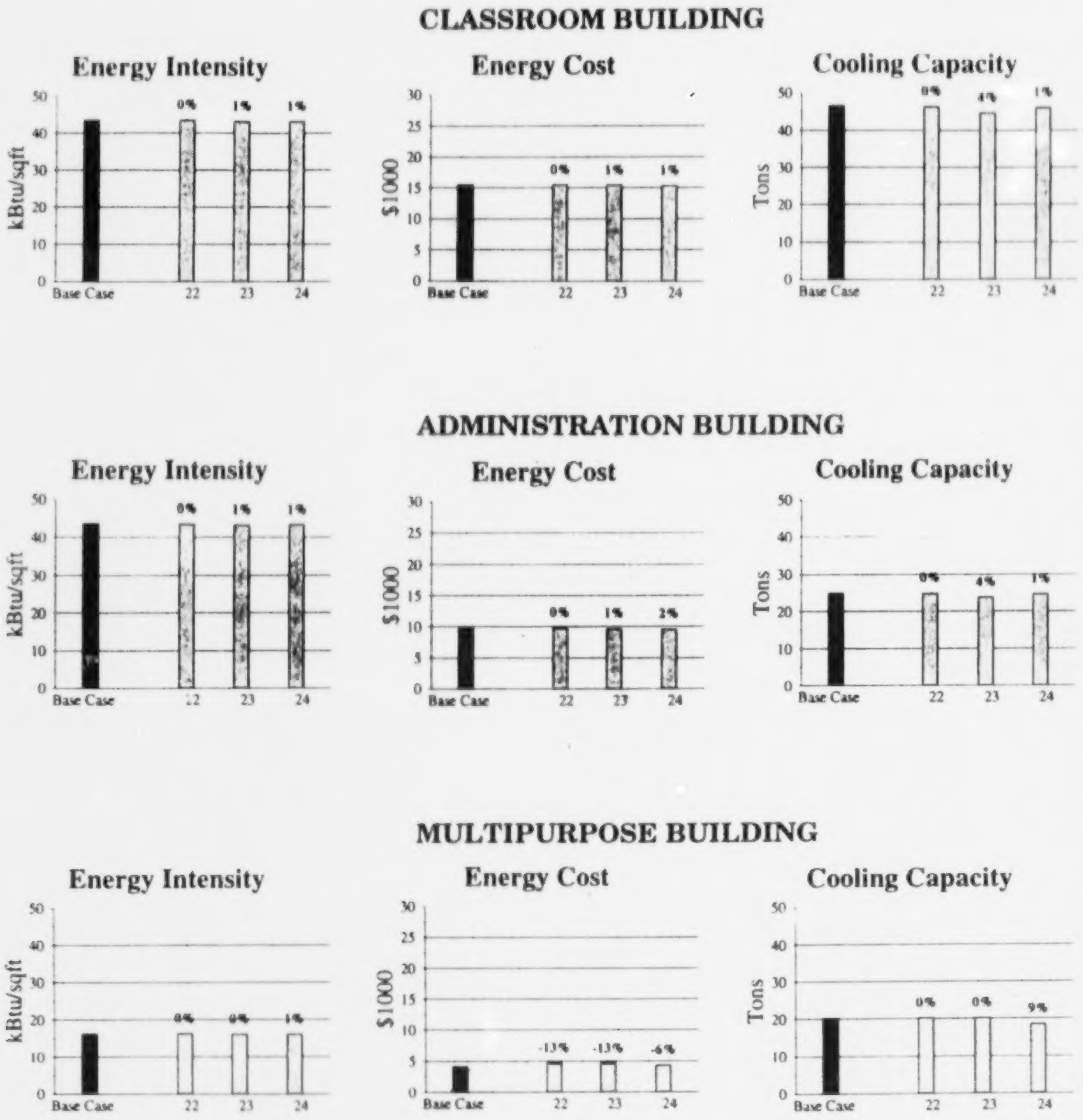

Trim lower branches to preserve view from window and avoid creating hiding places for vandals.
Half the distance of mature branch spread
9'

Figure 25. Safety precautions for positioning shade trees.

Window shading has a different role in energy conservation than that of wall shading and is covered under *Window Shading*.



22	2' Overhang
23	4' Overhang
24	Shade Trees

Figure 26. **Wall shading provides relatively small savings in accordance with the small portion of the peak HVAC load associated with heat gain for walls.**

3. Insulation

Although insulation commonly appears among cost-effective energy conservation measures for residential buildings, it is less effective in institutional and commercial buildings which are dominated by internally generated loads. In fact, insulation may trap heat inside at night when outdoor temperatures drop and heat loss would be beneficial.

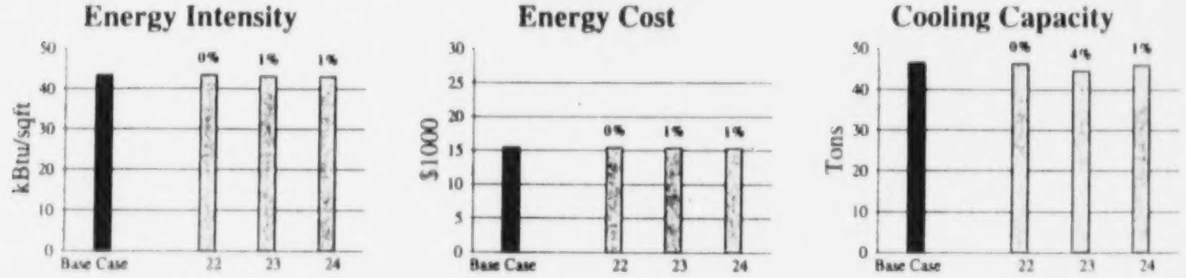
Several insulation enhancements were simulated (Figure 27) and only the R-30 roof insulation (Figure 27, #28) showed savings. Increased wall insulation beyond our R-5 Base Case, R-11 (Figure 27, #25) and R-19 (Figure 27, #26) both, increased annual energy consumption. This is probably because the nightly cycle of heat transfer between the inside and exterior of the building is hindered.

Heat generated by people and lights inside the building during the late part of the day lingers on after the air conditioning system has shifted into "unoccupied" mode. Meanwhile, the temperature outside and the temperature of the exterior surface drops (during regular school months). Heat is then conducted from inside surfaces to the outside and the higher the insulation, the slower the transfer of heat. The building interior is then warmer at start up of the cooling system the following morning.

Insulation has a positive impact on air conditioning loads up to a certain point, but has strongly diminishing returns. If any insulation above code level is used, it should go in the roof assembly where the majority of envelope heat gain occurs (excluding radiant heat gain through glazing).

The placement, interior or exterior, of rigid insulation on concrete block made little difference in annual energy consumption and, likewise, in time-of-day peaks. A common idea for residential construction is that insulation added to the exterior may shift the peak daily load to an "off-peak" rate period and therefore is superior; however, virtually no differences in the results for the two configurations were observed.

CLASSROOM BUILDING



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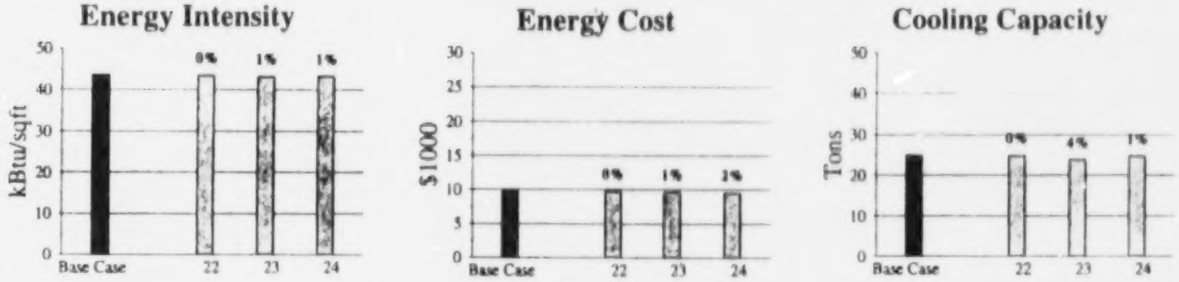
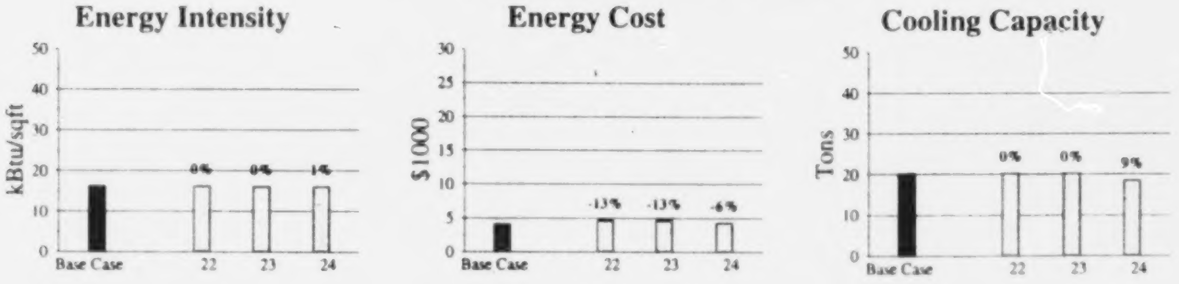


MULTIPURPOSE BUILDING



22	2' Overhang
23	4' Overhang
24	Shade Trees

Figure 26. **Wall shading provides relatively small savings in accordance with the small portion of the peak HVAC load associated with heat gain for walls.**

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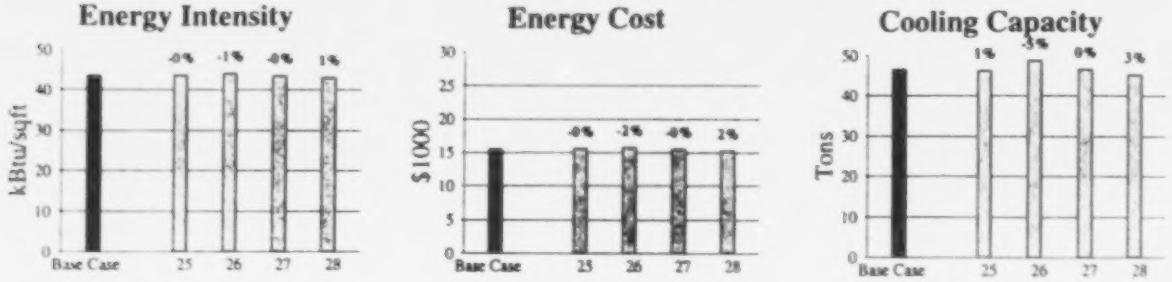

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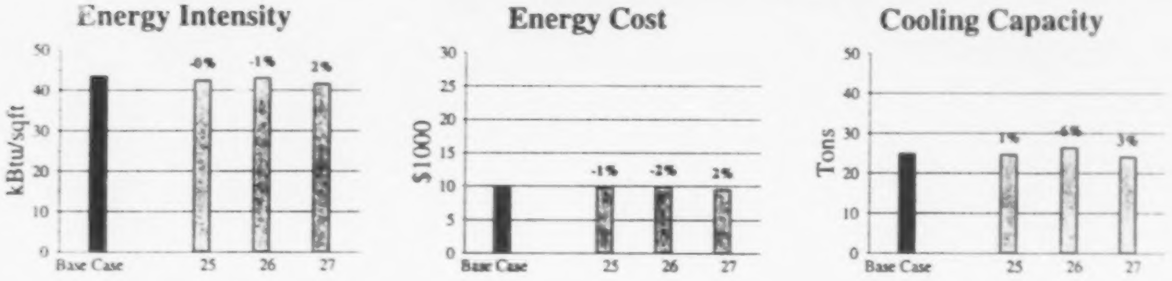
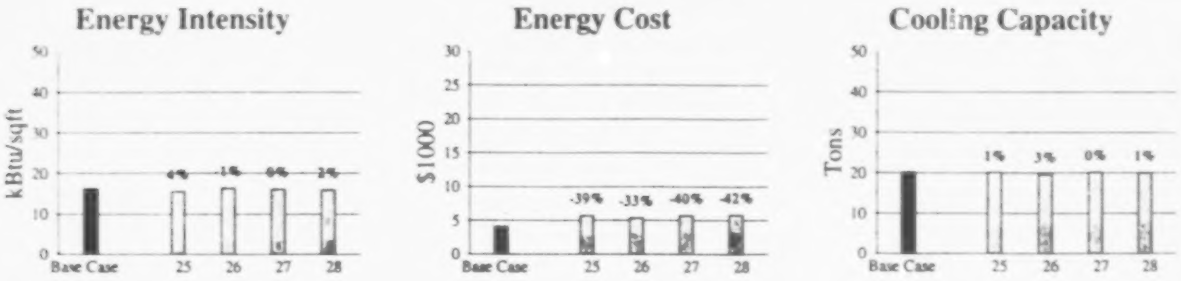


MULTIPURPOSE BUILDING



25	R-11 Wall
26	R-19 Roof
27	Insulation to Keep Interior of Wall
28	R-30 Roof

Figure 27. Wall insulation has little affect on school building energy use which are dominated by internally generated loads.

4. Consensus Recommendations

Code levels of insulation for educational facilities are adequate. However, modest savings (~3%) can be produced by increasing the ceiling insulation levels to R-30. Additional wall insulation beyond code levels is not effective.

If possible use a white reflective roof finish. This will provide energy savings of 3% or more. Energy savings may be twice this level if supply air ducts or chilled water lines pass through a plenum space between the roof an insulation located on the ceiling. Reflective roofing can be accomplished at virtually no cost by choice of white colored materials. These include, white metal roofing, white single-ply roofing membranes and white concrete tiles.

Use light colored finishes for building walls. This is essentially a no-cost option.

Strategically planted shade trees may offer some energy savings at a low cost if planted as seedlings. Locate trees on east, west and south sides of the building which are otherwise difficult to shade. Allow for future growth in their location.

Overhangs provide modest energy savings, but may be important to glare control if no other means of south window shading is available for daylight space. If so used, properly size the overhang length based on window height and separation from the roof line.

Section III

System Design

System Design Overview

In Section III, the design team deals with the largest end-use, HVAC, and often the largest load on that end-use, lighting. During *System Design*, designers should strive to:

1. Select an efficient lighting system (involving dimming if appropriate).
2. Select an efficient HVAC system and layout.

Lighting System and Component Selection

A majority of educational facilities use fluorescent lighting in classrooms, offices, conference rooms, libraries, and assembly areas. Each component of a fluorescent lighting system contributes to energy consumption, not just the lamp. Hence, each component should be selected with consideration for its impact on the energy consumption of the overall system. The primary reason for selecting an improved lighting system is increased lamp-ballast *efficacy* which can lead to reduced energy consumption, and consequently less heat production. System efficacy is the ratio of system output (in lumens) to system input (in watts). An improved system will either produce more lumens for the same power input or the same lumens with less power input.

Keep in mind that part of the savings achieved by more efficient lighting comes from the reduction of heat generated by the lights. As a rule of thumb, approximately 1 watt of increased HVAC electrical consumption accrues for every 4 watts of electricity consumed by lighting. Therefore, if the energy consumption of a luminaire can be reduced by 40 watts a total savings of 50 watts will be achieved (40 watts light savings + 10 watts HVAC savings). All of the electricity consumed by the lighting system gets converted either directly into heat or first into light and then into heat. With less power being supplied to the lights, less total heat is produced.

Lighting assemblies: Elements of a lighting system affect each other, so a combination of lighting components may behave differently than the components do separately. To account for this the data used to model these configurations was taken from lighting system experiments performed in occupied offices in 1993.

These studies, performed at the Florida Solar Energy Center, document energy consumption, work surface illumination, power factor, lamp wall temperature, and a variety of other parameters for 39 lamp-ballast-fixture combinations (Parker, Stedman and Sonne, 1994).

HVAC System and Component Selection

The principal job of the HVAC system in Florida is to provide comfortable space conditions for a learning environment and to provide adequate ventilation of outside air for building occupants. The HVAC system must deal with all the heat and moisture transmitted by the building envelope (external gains) and all the heat and moisture produced by occupants, lights, equipment, and processes (internal gains). By implementing the measures in *Schematic Design*, *Design Development*, and *Systems Design* to limit both external and internal gains, designers can expect lower sensible air conditioning loads. However, lowering sensible cooling loads will lower sensible heat ratios (SHR) necessary from HVAC equipment and challenge the designer. Space conditions will be more difficult to meet without the use of reheat systems, and room air motion may be reduced with variable air volume (VAV) systems..

Once loads have been reduced as much as possible, select a system appropriate for the facility and then choose the most efficient model available in each equipment category. High-efficiency motors may be added for fans and variable speed pump drives for variable volume systems. Careful attention should be paid to effectively meeting building ventilation requirements while providing sufficient dehumidification of outdoor air prior to its introduction to the interior environment.

To achieve successful HVAC design, the architectural members of the design team must closely communicate with the engineering members. If special efforts have been made to reduce the air conditioning load in the *Schematic Design* and *Design Development* phases, and no one informs the mechanical engineer, the building may not get the proper size cooling system. An oversized system will not run at maximum efficiency. On the other hand, the mechanical engineering members of the design team should feel free to make suggestions on how to decrease the HVAC load during design development. The nature of energy-efficient design requires communication and cooperation among members of different design disciplines working toward the same goal.

Strategies for System Design

- Efficient Lighting .... page 72
- Efficient HVAC .... page 84

		Energy Intensity	Energy Cost	Cooling Capacity	Electric Consumption	Gas Consumption	Incremental First Cost	Energy Cost Savings	Simple Payback
	CLASSROOM BUILDING	[illegible]	[illegible]	Tons	kWh	Therms	$	$	Years
30	F40, T12, Magnetic Ballast	45	16058	47	193231	99	6000	-577	-10
31	F34, T12, Magnetic Ballast, Open Diffuser, Parabolic Troffer	43	15383	46	185072	104	0	98	0
32	F34, T12, Electronic Ballast	40	14330	45	165414	118	3200	1151	3
33	F32, T8, Electronic Ballast	39	13854	44	166570	117	9700	1627	6
34	High-Efficiency Exit Sign	43	15291	46	183944	105	900	190	5
61	Occupancy Sensors	41	14492	45	174067	112	720	989	1
7	32W, T-8, Continuously Dimming Electronic Ballast	36	12936	42	154017	121	5400	2545	2
45	15 CFM per Person	48	17259	59	204413	129	*	-1778	0
46	TERS 5 CFM per Person	42	16848	45	180873	94	18800	-1367	-14
47	TERS 15 CFM per Person (compared to #45)	47	17165	59	203664	0	*	-1684	0
48	Optimal Start	41	15019	46	178288	64	5000	462	11
49	Enthalpy Economizer	43	15462	46	185909	104	0	19	0
51	Reheat Constant Volume	43	15264	47	184056	103	*	217	0
35	Centrifugal Chiller	39	13508	47	164311	103	*	1973	0
36	Screw Chiller	35	12686	47	151681	86	2400	2795	1
37	Gas Absorption Chiller	81	12970	47	127471	7654	*	2511	0
38	Ceiling Fans	33	10276	44	185771	86	3000	5205	1
39	Variable Speed Pumps	43	15237	47	182607	97	*	244	0
40	Non-Variable Speed Fans	46	22686	47	194949	99	*	-7205	0
41	Variable Temperature Constant Volume	42	15230	46	182307	31	*	251	0
42	Multizone Constant Volume	41	14754	45	179033	41	11	726	0
43	Dual Duct Constant Volume or Variable Volume	42	15195	46	183460	35	*	285	0
44	Four Pipe Fan Coil	34	11926	39	146562	83	*	3555	0
52	Unitary Heat Pumps	42	20802	47	183673	4	*	-5321	0
53	Packaged Single Zone Variable Temp DX Unit	37	14163	39	161450	0	*	1318	0
54	Packaged Multizone DX Unit	37	13430	38	160551	0	*	2051	0

* Data not available: Price varies too widely to approximate

	ADMINISTRATION BUILDING	Energy Intensity	Energy Cost	Cooling Capacity	Electric Consumption	Gas Consumption	Incremental First Cost	Energy Cost Savings	Simple Payback
		kBTU/sqft	$	Tons	kWh	Therms	$	$	Years
30	F40, T12, Magnetic Ballast	44	10132	25	127436	56	4050	-398	-10
31	F34, T12, Magnetic Ballast, Open Diffuser, Parabolic Troffer	42	9668	25	121872	61	4050	67	60
32	F34, T12, Electronic Ballast	39	8950	24	108546	74	2160	785	3
33	F32, T8, Electronic Ballast	38	8624	23	109341	73	6548	1110	6
34	High-Efficiency Exit Sign	42	9610	25	121148	62	900	125	7
61	Occupancy Sensors	41	9338	25	114421	68	720	397	2
7	32W, T-8, Continuously Dimming Electronic Ballast	35	8033	22	100663	77	3645	1702	2
45	15 CFM per Person	45	10412	27	129904	75	*	-677	0
46	TERS 5 CFM per Person	42	9583	24	120888	59	10000	152	66
47	TERS 15 CFM per Person (compared to #45)	43	10124	28	126969	0	*	-389	0
48	Optimal Start	42	9627	25	119139	39	5000	108	46
49	Enthalpy Economizer	42	9715	25	122309	62	2400	20	122
51	Reheat Constant Volume	42	9614	25	121439	60	*	121	0
35	Centrifugal Chiller	39	8726	25	111533	60	*	1008	0
36	Screw Chiller	37	8656	25	104658	51	2400	1079	2
37	Gas Absorption Chiller	117	12400	47	121069	7560	*	-2665	0
39	Variable Speed Pumps	42	9634	25	120680	57	3000	101	30
40	Non-Variable Speed Fans	44	14200	25	127275	60	*	-4465	0
41	Variable Temperature Constant Volume	41	9395	24	119839	36	*	340	0
42	Multizone Constant Volume	41	9336	24	118703	10	*	399	0
43	Dual Duct Constant Volume or Variable Volume	41	9598	24	121376	5	*	136	0
44	Four Pipe Fan Coil	35	7762	20	100892	41	*	1972	0
52	Unitary Heat Pumps	42	9722	25	121312	18	*	13	0
53	Packaged Single Zone Variable Temp DX Unit	37	8980	20	109230	0	*	755	0
54	Packaged Multizone DX Unit	37	8549	20	108769	0	*	1186	0
55	Packaged Terminal AC / Heat Pump	37	9090		109064	0	*	644	0

* Data not available: Price varies too widely to approximate.

	MULTIPURPOSE BUILDING	Energy Intensity kBTU/sqft	Energy Cost $	Cooling Capacity Tons	Electric Consumption kWh	Gas Consumption Therms	Incremental First Cost $	Energy Cost Savings $	Simple Payback Years
31	F34, T12, Magnetic Ballast, Open Diffuser, Parabolic Troffer	16.12	4055.05	22	507539	419.86	5385	14	0
32	F34, T12, Electronic Ballast	15.75	3911.23	20	490111	429.69	2872	157	0
33	F32, T8, Electronic Ballast	15.58	3846.25	20	482192	434.24	8706	222	0
34	High-Efficiency Exit Sign	16.07	4039.56	20	505699	420.32	320	29	11
7	32W, T-8, Continuously Dimming Electronic Ballast	15.32	3730.18	20	471362	437.12	4847	338	14
45	15 CFM per Person	21.36	5864.06	34	689505	498.94	*	-1795	0
46	TERS 5 CFM per Person	14.86	3595.91	17	460923	410.51	8000	473	0
47	TERS 15 CFM per Person (compared to #45)	16.13	4067.08	20	509121	415.86	8000	2	0
48	Optimal Start	14.91	3902.62	20	487187	328.5	5000	166	0
49	Enthalpy Economizer	16.12	4059.39	20	507419	420.69	2400	9	0
51	Reheat Constant Volume	16.00	4007.71	20	503035	419.09	*	61	0
35	Centrifugal Chiller	3370.3	4698	20	438509	418.93	*	-629	0
36	Screw Chiller	2563.3	3566	20	383276	356.82	2400	502	0
37	Gas Absorption Chiller	3074.7	3833	20	298421	3110.5	*	235	0
39	Variable Speed Pumps	3935.8	5500	20	490873	403.77	3000	-1431	0
40	Non-Variable Speed Fans	4544.4	6359	20	578936	415.62	*	-2290	0
41	Variable Temperature Constant Volume	13.77	4008.28	20	513076	87.25	*	60	0
42	Multizone Constant Volume	13.16	3690.1	19	480097	119.1	*	379	0
43	Dual Duct Constant Volume or Variable Volume	13.41	3810.93	20	493317	106.81	*	258	0
44	Four Pipe Fan Coil	10.99	2554.21	16	337521	315.35	*	1514	0
52	Unitary Heat Pumps	13.68	4051.14	18	494644	138.79	*	17	0
53	Packaged Single Zone Variable Temp DX Unit	11.99	3947.03	20	468925	0	*	122	0
54	Packaged Multizone DX Unit	10.98	3532.28	20	429487	0	*	536	0
55	Packaged Terminal AC / Heat Pump	11.70	4223.14	17	457838	0	*	-155	0

* Data not available: Price varies too widely to approximate.

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STRATEGY: Efficient Electrical Lighting

OBJECTIVE: Provide superior electrical illumination with reliable systems that require less power and produce less heat than standard practice systems

CONSIDERATIONS: Electrical lighting impacts building energy use in two ways. First, energy consumed by lights constitutes a major portion (25%) of overall building consumption. Second, all power consumed by lighting systems is eventually converted into heat. This makes up a sizable portion of the air conditioning sensible load in school buildings.

Design teams have three options for reducing general lighting power consumption. First, select more efficient system components such as ballasts, lamps, lenses, and troffers. With this strategy, strive to achieve the highest lumen output per watt input, or efficacy, for the fixture as a unit. Second, provide occupancy sensors, time clocks, or some other automatic or manual controls that limit the length of time the lighting system operates. Third, provide mechanisms to dim electrical lighting when sufficient natural lighting is present.

Providing adequate lighting must always remain a top priority when considering any innovative lighting systems since the quality and quantity of light directly impacts the comfort and productivity of the students and instructors..

ECM OPTIONS:

1. Efficient System Components
    a. Ballasts
    b. Lamps
    c. Fixtures
    d. Ambient and Task Lighting
    e. Exit Signs
2. Automated Lighting Controls
    a. Occupancy Sensors
    b. Continuously Dimming Electronic Ballasts
3. Consensus Recommendations

1. Efficient System Components for General Lighting

Designers have many new options for increasing the lamp-ballast efficacy. The following descriptions serve as an introduction to some of the alternative products to standard 34 watt, T-12, energy efficient magnetic ballast configuration used in the base case simulation..

a. Ballasts

Designers have three basic options for operating fluorescent lamps. The energy-efficient magnetic ballast, the cathode cutout ballasts, and the high-frequency electronic ballast. The dimming electronic ballasts will be discussed later.

The *energy-efficient magnetic ballast* uses less energy than a standard core-coil ballast because copper wire is used instead of aluminum wire. Most ballasts sold in America today are energy-efficient magnetic ballasts; however, the trend is moving toward electronic ballasts. *Cathode cutout ballasts* combine magnetic components with electronic switching circuits to remove filament power after the ballast has performed its start-up duty. This improves system efficacy by about 5% but may reduce lamp life. The high-frequency *electronic ballast* converts the 60 Hz line voltage supply into high frequency (above 20 kHz) power. This high frequency power serves the same purpose as the 60Hz power that magnetic ballasts produce: it excites an arc in the lamp to make light. However, fluorescent lamps have been shown to operate at a 10% to 15% higher efficacy with high frequency input (LRC Specifier Reports) which the electronic ballast can supply (Figure 28).

Electronic ballasts are available for T-12, T-10, and T-8 lamps and can be used with almost any fluorescent fixture or housing. Electronic ballasts also consume less energy and run cooler than the magnetic type, resulting in about a 10% reduction in ballast losses. Addi-tionally, electronic ballasts can produce minimal harmonics, meaning quieter operation and less interference with other electrical devices.

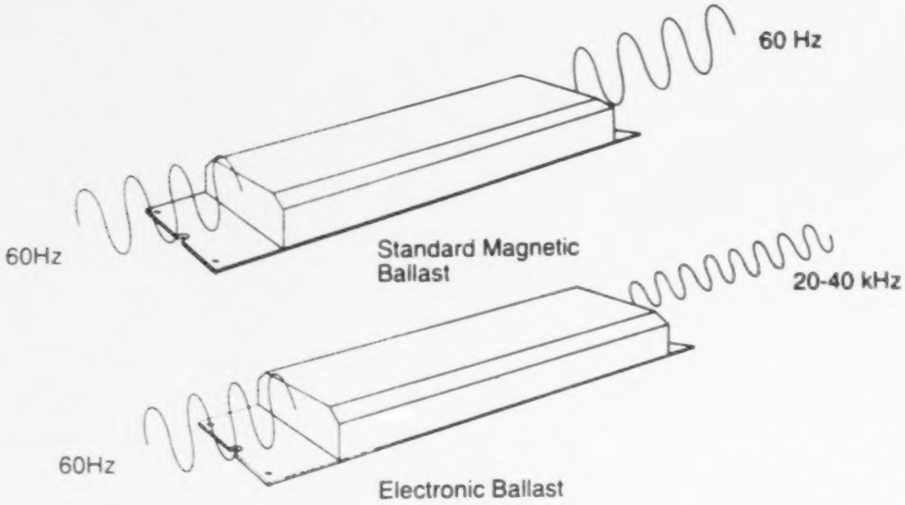


Figure 28. **Magnetic ballasts (top) transmit 60 Hz line voltage ot fluorescent lamps whereas electronic ballasts (bottom) provide high frequency (20-40 Hz) to fluorescent lamps yielding 10% to 15% higher efficacy.**

A single electronic ballast can run between one and four lamps as opposed to only two lamps for magnetic ballasts. This lends great flexibility to lighting design and can reduce the number of required ballasts. Lamp output, however, changes slightly with each incremental increase in the number of lamps per ballast. The factor that determines how much of the maximum light a lamp actually produces is called *ballast factor* (i.e., a lamp rated at 3050 lumens driven on a ballast with a ballast factor of 0.95 will only produce 2900 lumens). Ballast factors greater than 1.00 will decrease lamp life.

Both rapid-start and instant-start types offer savings; however, the instant-start ballasts, which respond immediately when switched, may shorten lamp life because they keep the lamps in a constant "ready" state.

Although some manufacturers estimate that their electronic ballasts will last 20 years, the average life of an electronic ballast is unknown. Careful consideration should be given to warranty (available up to 5 years) and historical performance of a particular model.

Design teams should avoid coupling electronic ballasts with power line carrier (PLC) type energy management systems due to possible interference.

Other important characteristics to consider are surge protection, power quality (THD less than 20%), crest factor (less than 1.7), and power factor. In retrofit applications the power company should be consulted regarding financial incentives and minimum requirements for electronic ballasts. For example, electronic-magnetic hybrid ballasts may offer excellent efficiency and quality for utility rebates, yet cost less than a fully electronic ballast. Similarly, lower THD ballasts will usually cost more than high THD ballasts. The power company may recommend or require THD be less than a specified value to qualify for the rebate. A target THD of 20% is reasonable. Values significantly higher than this may cause harmonic related disturbances in the electric system, such as transformer or neutral conductor heating.

The potential for electric surge damage to electronic ballasts is not fully understood and may be an most important cost issue related to electronic ballasts life. It is recommended that the manufacturer of the ballast be consulted to determine how or if the ballast is internally protected. In all cases it is recommended that at least two stages of building power system surge protection be installed in front of the lighting ballast branch circuits.

b. Lamps

Lamp efficacy (Figure 29) and the configuration of lamps in a fixture have great impact on the efficacy of the fixture as a whole. Three sizes of lamps are now available: T-12 (1½-inch diameter), T-10 (1¼-inch diameter), and T-8 (1" diameter). The T-12 lamp in two or four lamp fixtures with energy-efficient, magnetic ballasts has the lowest first-cost and is the most common choice; however, the efficacy of this configuration falls below many other config-urations available today.

The T-10 lamp commonly replaces the T-12 in retrofit applications because it can be used with the same magnetic ballast as the T-12 lamp. The T-10 offers a higher efficacy (higher light output for the same amount of power input), which means that the number of lamps per fixture can often be decreased while maintaining the same light level. With fewer lamps housed in a fixture, less light is trapped in the top part of the troffer, increasing the efficacy of the fixture. Unfortunately, T-10 lamps are currently over three times as expensive a T-12 lamps and they place greater loads on the ballasts, which could result in ballast failures in older retrofit applications.

The T-8 lamp is used for both new and retrofit applications; however it requires a compatible ballast. These smaller lamps do not require any different kind of wiring techniques, and they offer many advantages over standard T-12 lamps. They have higher efficacy (lumens/watt) and trap less light in the fixture than the larger diameter T-12 lamps, increasing the efficacy of the luminaire. T-8 lamps with electronic ballasts, which operate at a higher frequency than magnetic ballasts, have no perceivable flicker. They also offer improved color rendering compared to the standard, cool-white T-12 lamps resulting in improved visual quality.

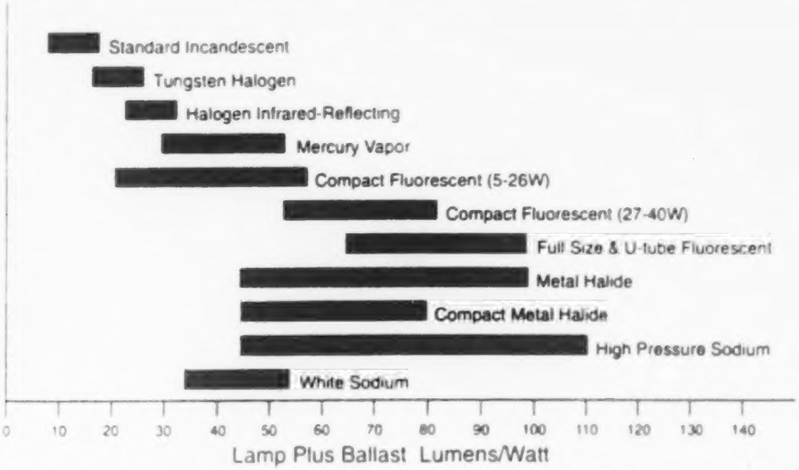


Figure 29. **Luminous efficavy, light out-put in lumens per power in-put in watts, for various lamps.**

c. Fixtures

Standard fluorescent luminaires house between one and four lamps in a rectangular troffer with prismatic diffuser. The conventional design of these fixtures limits the amount of light that actually is distributed. A portion of the light from the top of the lamps projects up and reflects back down off the troffer top but never makes it past the lamps. This light bounces around in the corners of the fixture and is blocked by the lamps themselves. The problem can be avoided by either allowing more free space around the lamps (less lamps per fixture) or by using specular reflectors that more effectively redirect light from the top of the lamps. Specular reflectors not only reshape the interior of the luminaire, but offer an increase in fixture efficacy as well. They can work very well in older fixtures where reflective paint has yellowed due to age. Often a two-lamp regular or high output T-8 luminaire with reflectors can be substituted for a standard four-lamp T-12 fixture. This configuration will have an increased first cost but the energy savings and lamp replacement cost saving should offset this quickly. Tandem wiring of four-lamp ballast to two two-lamp luminaires can offset this first cost substantially and increase system performance.

An alternative to prismatic diffusers is a parabolic louver. Parabolic louvers are open grids (Figure 30)that transmit light in a different way from prismatic diffusers. The grid spacing varies from half an inch to several inches. As a general rule the efficacy of the fixture decreases directly with the cell size of the grid. Parabolic louvers tend to have a higher visual comfort probability but are not as efficient at light distribution as the prismatic diffuser. The parabolic louvers project light directly below the fixture in a distinct cone pattern whereas the prismatic diffusers throw light in all directions. Parabolic louvers are most appropriate for rooms with computers and video display terminals (VDTs) since they cause less disability glare than prismatic diffusers. One advantage of the parabolic louvers is that they do not trap heat in the fixture as do prismatic diffusers. This lowers the lamp wall temperature.

Fluorescent lamps operate optimally when lamp wall temperature is about 100°F. Prismatic diffusers can cause cathode end temperatures to climb above this optimal temperature, causing reductions in lamp efficacy.

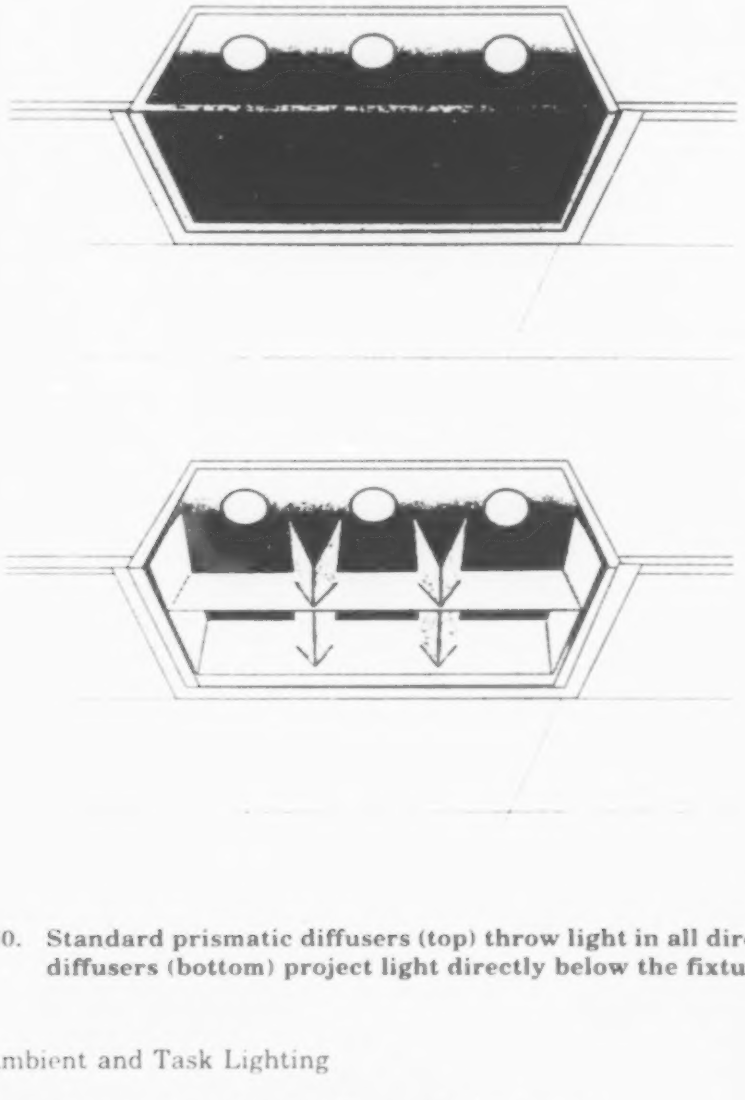


Figure 30. **Standard prismatic diffusers (top) throw light in all directions whereas parabolic diffusers (bottom) project light directly below the fixture.**

d. Ambient and Task Lighting

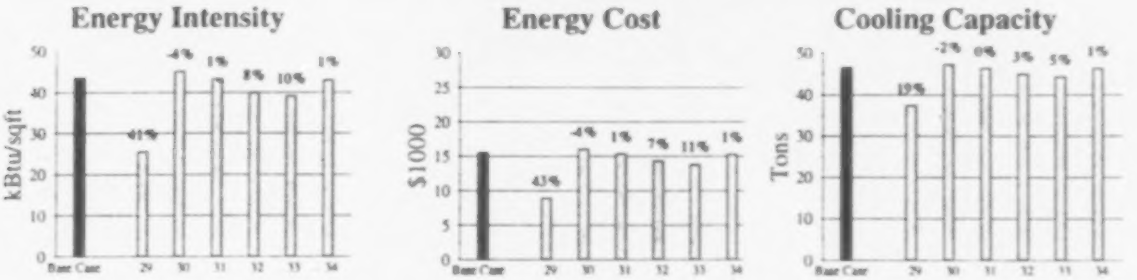
Compact fluorescent lamps offer many advantages over incandescent lamps and are used widely for task lighting. Compact fluorescent lamps are available in a wide range of sizes and configurations. They last about ten times as long as incandescent lamps and some offer excellent color rendering. A 13-watt compact fluorescent lamp provides about the same illumination as a 60-watt incandescent lamp and produces considerably less heat. This characteristic offers extra appeal for task lighting since the heat generated by task lighting warms the user's immediate work area above that of the rest of the space.

One effective strategy used in VDT offices is to combine low ambient light levels (≈30 footcandles) with a small task light to use for reading and writing. This may not be practical in a classroom setting, however.

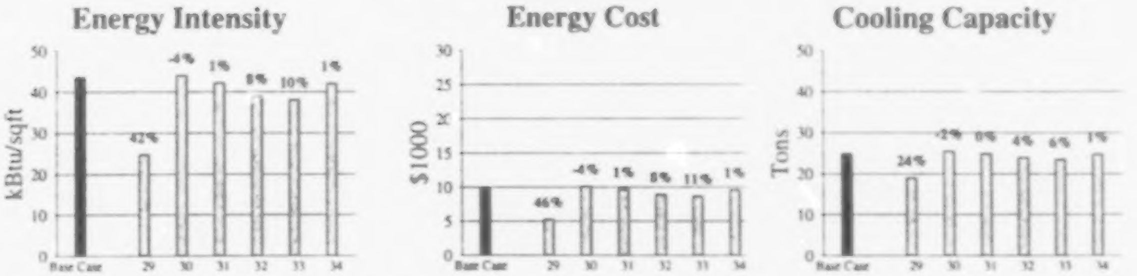
e. Exit Signs

Exit signs operate 24 hours a day, 365 days a year. In a typical building having six to eight signs, this constitutes a significant cumulative energy use. Several options to incandescent exit fixtures offer less energy consumption and lower maintenance. Electroluminescent exit signs use no power and last for up to 20 years. They require no wiring and virtually no maintenance. LED exit signs and fluorescent exit signs also offer large savings with little maintenance and both cost less than electroluminescents. They use standard wiring and have a long life expectancy. The LEDs have a projected life ranging from 700,000 to over 5 million hours, but the standby battery must be replaced every 80,000 hours. The fluorescent fixtures have a life of about 15,000 hours. Although, they make up only a small fraction of the building lighting load, use of LED or flourescent exit signs was found to be very cost effective.

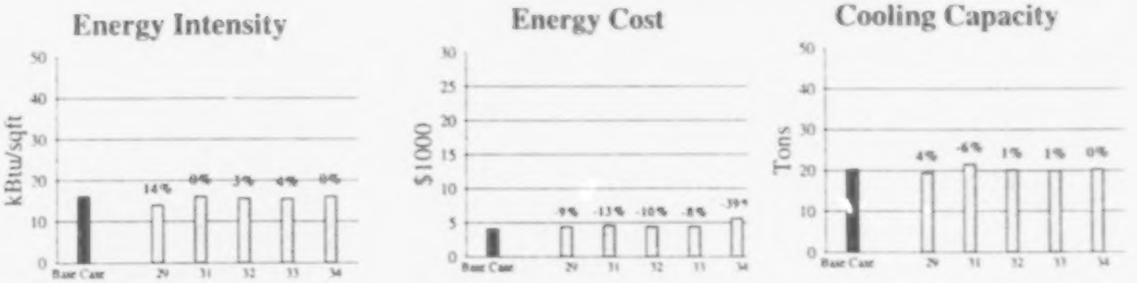
CLASSROOM BUILDING



ADMINISTRATION BUILDING



MULTIPURPOSE BUILDING



29	No Electrical Lighting	32	F34, T12, Electronic Ballast
30	F40, T12, Magnetic Ballast	33	F32, T8, Electronic Ballast
31	F34, T12, Mag Ballast, Open Diffuser, Parabolic Troffer	34	High-Efficiency Exit Sign

Figure 31. Reducing electrical lighting reaps a large saving because lights both consume electricity and produce heat. Electronic ballasts coupled with either T-12 or T-8 lamps produced impressive savings.

2. Automated Lighting Controls

Simply turning off the lights in unoccupied rooms is good conservation practice. The possible exception would be spaces where lights serve another purpose, such as to maintain safety or security (egress hallways for night school classes), to imply that visitors may enter a space (lights in the library on open house night), to maintain light in spaces where occupants aren't moving much (reading or study rooms) or with fixtures that require a warm-up time (gymnasium HID lights). So, for the sake of such circumstances, an override switch for automated lighting controls should be provided along with clear guidelines about appropriate times to use the override.

a. Occupancy Sensors

Occupancy sensors are electrically powered controls which may replace the light switches in small rooms such as offices or be placed in the ceiling for more accurate control in large areas such as classrooms and conference rooms. They detect changes in the environment in one of two ways. *Passive infrared (PIR) sensors* see a heat image in a space and turn lights off when the image remains constant for a specified period. *Ultrasonic sensors* send and receive sound waves. They detect changes in the sound image of the space and turn lights off when the image has been constant for a specified time. The time delay prior to automatic switching can be adjusted for occupancy sensors. Depending on the manufacturer ranges are available from three seconds to 30 minutes. Some units use both sensing methods to reduce the chance of false readings. Proper commissioning of occupancy sensors in terms of time delay settings and sensitivity is essential for user acceptance and should be an integal part of project specifications to ensure proper performance.

The type and manufacturer of a sensor determine the physical range of detection (size of the heat or sound image) and manufacturer information should be reviewed to find the appropriate sensor for each space. Manufacturers will provide layouts free of charge. For small spaces, such as copy rooms, conference rooms, and offices, one sensor will likely be adequate. Multiple sensors will provide better control for large open spaces such as auditoriums. Payback is fastest in seldomly used areas with multiple fixtures such as conference rooms.

Spaces likely to reap the greatest benefits are those for which no one feels responsible. These common-use rooms, such as copy rooms, break rooms, conference rooms, mail rooms, supply rooms, bathrooms, reading rooms, media rooms, community work rooms, etc., may be inappropriately lit all day because no one has thought about turning off the lights or because "We always leave them on." Occupancy sensors will even benefit spaces such as offices and classrooms where occupants leave the room during the course of the day and return much later, or not at all.

After everyone has left the building for the day, occupancy sensors ensure that the lights will be turned off. Energy management systems also offer this capability, but at a much higher cost. Occupancy sensors can also provide a security alert. If police know that a school should be dark at night, lights will help signal a possible intrusion.

b. Continuously Dimming Electronic Ballasts

Ballasts with dimming capability can play a significant role in the success of a daylighting plan. No amount of glazing design and layout can ensure the success of a daylighting strategy if the electric light output can not be reduced with automatic dimming controls when natural light meets or exceeds the desired lighting levels. Electronic dimming ballasts reduce power consumption and light output either in distinct steps or continuously over the full range of rated output. Generally, continuously dimming controls are preferred to stepped controls due to greater occupant acceptance of the continous systems.

Magnetic ballasts can be configured to dim in response to daylighting using autotransformers or other wave chopping techniques, but only down to about 40% of light output before flickering becomes pronounced.

Dimming ballasts with conventional manual controls are available but require occupants to pay attention to and control the light level in response to daylighting. This has all the associated cost of dimming with no guarantee of energy savings since cooperative and vigilant behavior is required.

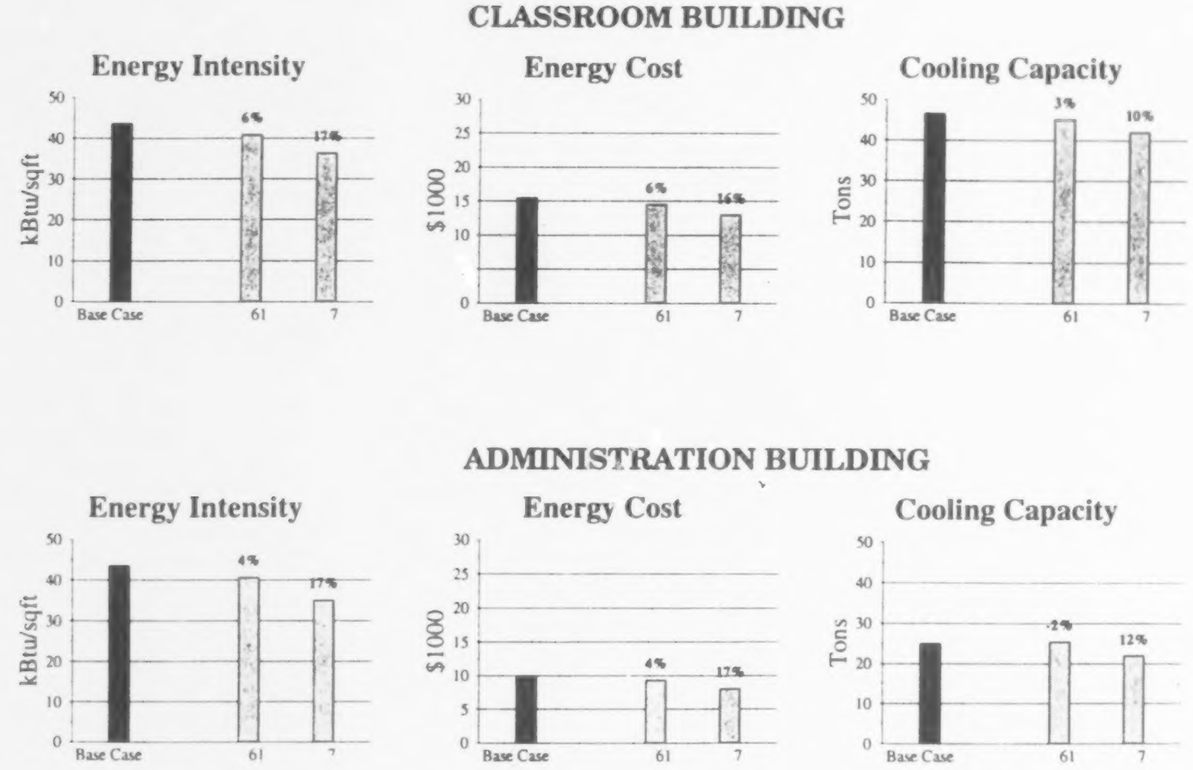
Electronic ballasts have no perceivable flicker, even when dimmed down as low as 5% of output because of the high frequency of the input current. Additionally, the electronic ballasts offer higher efficiencies at reduced power than magnetic ballasts.

Continuously dimming electronic ballasts work in conjunction with a photometric light sensor which is mounted on the ceiling. The photometric sensor sends an electronic signal (DC voltage) to the ballast, which actually controls the light output level, reducing power to the lamps when ambient light levels are sufficient. Some sensors feature a potentiometer that can be calibrated to adjust the dimming range. After installation, a technician adjusts the potentiometer to dim when the light level (measured at the *work plane*, not the ceiling) meets the desired level for the occupants. In general, it is recommended that project specifications for daylighting projects with dimming controls include requirements for system commissioning. This will insure proper function of the daylighting control system and sufficient lighting levels during nighttime hours.

Some manufacturers produce dimming sensors that can control multiple ballasts, which reduces first costs. But with fewer fixtures per sensor, a more accurate light level will be measured for the area each fixture is actually illuminating. One method of configuring dimming controls places a single sensor for each bank of light fixtures in adjacent spaces that receive the same daylight exposure. This configuration must be provided with override controls for individual rooms to allow for projection activities and occupancy variations. Additionally, it makes no allowances for individual room conditions such as uneven shading. Unless rooms are identical in all aspects, this configuration may cause undue discomfort in some parts of the zones. A more expensive method provides one sensor per ballast, yielding superior accuracy in daylight dimming light in a specific space. A compromise with a single light sensor controlling a bank of similarly located lamps is often the best choice.

Remember that all the ballasts connected to a sensor will dim according to the light level at the point of the sensor, regardless of the actual light level below the lamp. For classrooms with rows of lighting parallel to windows, consider one central sensor per row or two sensors per row of dimmable fixtures for an adequate response to available natural lighting.

In consideration of circuitry, the daylit space should be divided into several zones. Zones not near daylighting apertures may receive very little if any natural light, and hence will not benefit from dimming capability. The depth of a daylight zone, and consequently the number of rows of fixtures benefitting from dimming ballasts depends on the design of windows and exterior shading. Use of available computer software can aid in predicting available daylight at different points in a space at different times of the year.



61	Occupancy Sensors
7	32W, T-8, Continuously Dimming Electronic Ballast

Figure 32. Reducing the run time of the lighting system yields two rewards: reduced electrical consumption and reduced heat generation. *Occupancy sensor* savings shown here are a conservative estimate because the research team could not locate any empirical third party sponsored data documenting the actual savings of this device. *Continuously dimming electronic ballasts* automatically dim lights to strike a balance between electrical and natural lighting that meets lighting requirements. They are, however, only one component of a daylighting plan.

3. Consensus Recommendations

Choose an efficent combination of lamps, ballasts, diffusers and troffers for the facility lighting system. The use of T-8 lamps with an electronic ballast and an appropriate luminaire is often an excellent choice.

Consider lower ambient interior lighting levels with task lighting for non-classroom spaces with heavy use of video display terminals (VDTs).

Specify fluorescent or LED type exit sign lighting.

Use occupancy sensors to control spaces with changing occupancy. Specify that such controls will be commissioned such that time delays are properly set and device sensitivity is adjusted.

Use continuously dimming electronic ballasts with photosensors to control electric lighting in daylit zones. Specify that such systems be commissioned to ensure that controls function properly and light levels are adequate during non-daylit hours.

STRATEGY: Efficient HVAC Systems

OBJECTIVE: Provide superior conditioned environment with low energy consumption.

CONSIDERATIONS: Selection and design of heating, ventilating, and cooling (HVAC) systems embodies complex relationships, many of which relate directly to the comfort and well being of occupants. When dealing with humidity control and ventilation, health must always take precedent over energy issues. In addition to the urgency of indoor air quality needs, engineers are faced with a wide variety of options for accomplishing the same goal.

ISSUES and ECM OPTIONS:

1. System Planning
2. Ventilation Rates
3. Dehumidification
    a. Dehumidification Technologies
    b. Ventilation To Offset Cooling Requirements
4. Cooling Systems
    a. Central Chillers
    b. Condensing Systems
    c. Packaged Terminal Air Conditioners
    d. Unitary Heat Pump
    e. Incremental Heat Pump
    f. Room Air Conditioners
    g. Rooftop Units
5. Air Distribution Systems
    a. Constant Air Volume
    b. Variable Temperature Constant Volume
    c. Variable Air Volume
    d. Low Temperature Air Systems
    e. Dual Duct
    f. Duct Energy Losses
    g. Air-and-Water Systems
6. Fans, Drives and Controls
7. Energy Management Systems and Controls
8. Variable speed pump drives
9. Consensus Recommendations
    a. Cooling Systems
    b. Ventilation
    c. Dehumidification

1. System Planning

HVAC systems for educational facilties should be designed with the awareness that various portions of educational facilities may be used according to varying seasonal schedules. This, in turn, may suggest adaptation of HVAC equipment selection to meet the differing annual schedules. For instance, libraries generally require year round space conditioning and effective humidity removal even during vacant periods. On the other hand, the schedule of classrooms may be quite seasonal. Other spaces, such as auditoriums are only intermittantly occupied while school administration facilities often operate for a month or more beyond the school year. Since it is not desireable to operate an entire chiller plant during the summer to solely serve a library or administrative facility, secondary supplemental HVAC systems should be considered in planning for educational facilities used beyond the regular school year.

2. Ventilation Rates

Current Florida regulations (Florida Administrative Code; Chapter 6A-2) require a minimum of 5 cfm of outside air per student. Recently, however, ANSI/ASHRAE Standard 62-1989 has recommended a minimum of 15 cubic feet per minute (cfm) per person for classroom buildings.[4] Research has shown that ventilation rates of 15 cfm per student are necessary to hold interior CO_2 levels below 1,000 ppm (Downing and Bayer, 1993). Moreover, Florida schools have experienced a continuing problem with increases in illnesses and indoor air quality (IAQ) complaints from students and staff. Although reduction of pollutant source strength is fundamental towards addressing this issue, increased levels of ventilation are often seen as desirable to reduce remaining interior pollutant concentrations. However, in hot and humid climates such as Florida, the introduction of this increased fraction of outside air into the building, coupled with high internal latent loads from students, may lead to unacceptable relative humidities if improperly designed and operated.

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[4] Recently, (June, 1994) ASHRAE has interpreted the 15 cfm per student requirement to allow the use of *average* classroom occupancy rates, rather than design occupancy with the priviso that the ventilation rate never be reduced below 50% of the recommended rate (7.5 cfm)

Although the ASHRAE outdoor air ventilation minimums can be widely observed in office buildings, applica-tions in classrooms have been limited. In addition, higher occupant densities in schools require increases in the outdoor air requirement by up to 30% (Wheeler, 1991). This leads to increased HVAC capacity requirements to meet the increased load, as well as greater difficulties in achieving acceptable interior humidity levels. Although increased ventilation rates will increase energy consumption during the times when the building is occupied and the ventilation is required, proper control of the introduction of outside air depending on space occupancy can significantly reduce the energy-related costs. Many previously designed Florida facilities drew in inadequate amounts of outside ventilation air during occupied periods, but had no option for reduction of ventilation during unoccupied periods.

The use of ventilation controls, based on CO_2 sensors can be a very effective method of providing for occupancy based ventilation control. This is often useful in portions of the facility characterized by high occupancy density for relatively short periods of time. Such areas include auditoriums, gynasiums, cafeterias and classrooms. Under CO_2 sensor control, these areas receive the design ventilation rate during periods of occupancy, but reduced outside air during unoccupied periods. According to the current interpretation of ASHRAE 62-1989 the floor during unoccupied periods could be 50% of the design ventilation rate. A Florida engineering firm specializing in IAQ mitigation provides a minimum ventilation rate of unoccupied spaces of 0.14 cfm per square foot of conditioned floor area when no special pollutant sources are recognized.

Outside air added to the conditioned space obviously must be exhausted. In general, it is advan-tageous to design for systems where the exhaust air is approximately 90% of the outside air intake to maintain the building at positive pressure (Morawa, 1993). This ensures that most air entering the building is preconditioned. However, exhaust air fans must be interlocked to associated air handlers and placed on independent schedules to assure that buildings remain at positive pressures.

With all mechanical ventilation systems, care should be taken that supply air is properly filtered. Outside air should be drawn through a mesh filter with supply air passed through a medium/high efficiency filter prior to introduction to the conditioned space. Return air should also be filtered. One Florida engineering firm recommends that a minimum of six air changes per hour be designed into the ventilation rate to properly filter a room. Particular care should be exercised with VAV or other systems where the air flows to spaces are modulated to be certain that face velocities are sufficient to provide effective filtration.

3. Dehumidification

In addition to increased energy use, control of indoor relative humidity (RH) becomes a challenging design problem. It is established that the lack of proper humidity control can lead to increased illness and IAQ complaints (Arundel et al., 1986). ASHRAE Standard 55-92 defines that space humidities should not exceed 60% RH at any temperature.[5] There are numerous strategies to controlling relative humidities while admitting more ventilation air. They are:

a. Dehumidification Technologies

Conventional Systems: Conventional AC systems primarily control the temperature and not the humidity level. As a first step, effective humidity removal using packaged and unitary equipment or fan coils critically depends on not over-sizing the equipment for the laod. Newer Energy Management Systems (EMS) allow explicit monitoring and control of space relative humidity. These should be considered particularly where interior moisture levels are likely to be of concern (i.e.

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[5] One Florida engineering firm sees the 60% RH as an absolute upper limit. With relative humidities around 60% they found that active teachers required air temperatures below 74°F or reported feeling uncomfortably warm. In addition, classrooms with large amounts of electronic equipment also require lower thermostat temperatures due to localized warm spots around the computer equipment. Thus, maintenance of relative humidities below 55% may reduce occupant complaints and allow operation of systems at higher internal temperatures.

with higher ventilation rates). However, it should be recognized that EMS controls alone cannot mitigate humidity concerns since humidistat control without means of reheat may over-cool the conditioned space. Even so, there are several operationally related suggestions that can help to reduce moisture levels with conventional systems:

- Reduce supply air flow: Reducing supply air flow in direct-expansion (DX) systems will decrease air coil velocity and result in increased moisture removal. It will also, however, somewhat reduce system relative efficiency. This can be partly offset by utilization of multi-speed blowers which can save electricity otherwise used for fan power. However, reducing the air flow to DX coils should only be done with electronic and pressure/temperature regulated coils. DX coils using capillary tube control for metering refrigerant flow are not capable of providing predictable control over a wide range of operating conditions. Also, it should be kept in mind that lowering the air flow may affect air filtration and the adequacy of ventilation air supplied to conditioned spaces.

- Lower chilled water temperature: Lowering the chilled water supply temperature will increase the relative moisture removal although it may also reduce system chiller efficiency and may require increased need for supply air reheat. This can be somewhat offset, however, by lower fan power requirements if a variable speed fan system is used.

Reheat: Adding sensible (non-latent) heat to a school's interior will increase the fraction of time that the cooling system operates and removes moisture. Previously, the most commonly used strategy to control humidity was to use electric reheat coils to increase the compressor run-time of thermostatically controlled constant volume systems or with Variable Air Volume (VAV) systems when the minimum cfm ratio is reached. Humidistats are often used with constant volume reheat systems. However, using electric reheat is very energy-intensive and must be avoided. In any case, the use of reheat should be minimized by the use of controls because it increases space cooling energy use. Since Florida state law prohibits electric reheat, other reheat sources must be used with hydronic coils. These can include natural gas, solar hot water and reclaimed condenser heat.

Heat Recovery: With chiller systems, two condenser tube bundles can be used to capture some of the rejected heat for heating the water loop used for reheat. One of the condenser tube bundles is piped to the cooling tower with the other piped to the building hot water circuit. The chiller then operates as a straight chiller when there is no call for heat. The other bundle operates as a heat pump to reject heat to the heating circuit up to its maximum capacity. Supplementary heat for the water loop can then be provided by a natural gas boiler.

Hot-gas Bypass: Some packaged systems have provision for hot-gas bypass. At low cooling loads, a valve routes compressed hot refrigerant gas back to the compressor suction inlet, creating lower flow though the main refrigerant loop. This allows the compressor to provide reduced cooling at low loads even though there is no reduction in electrical demand. Additional moisture is removed since the compressor on-cycle time is increased, although at the cost of cooling system performance. Thus, a 10 EER packaged unit operating with 50% hot gas bypass would drop the energy efficiency ratio to only 5 Btu/W. Also, hot gas bypass does not provide additional dehumidification unless the air flow on the coil is reduced proportionately. This means that hot gas bypass will be completely ineffective for constant volume systems. In general hot-gas bypass is inefficient and should be avoided.

Central Fresh Air Units: Outside air is draw into a central unit which uses a direct expansion (DX) vapor compression machine or chilled water with a low sensible heat ratio (SHR) to remove humidity from the moist air prior to its introduction into the building's interior (These units may be a special case where hot-gas bypass is acceptable). The relative efficiency of the DX equipment may be lower than the normal cooling equipment, but saves energy since the introduced outside air is dehumidified, greatly reducing the need for reheat of supply air under low-load conditions. Generally, DX units are more effective at removing moisture than chilled water systems. Other methods can be used with fresh air units: run around coils, face and by pass dampers, desiccant dehumidification, total energy recovery systems and heat pipes.

Desiccant Dehumidification: Conventional HVAC systems remove humidity by passing the supply air across a cooling coil maintained at a low enough temperature so that water vapor will condense on the coils as liquid. With desiccant dehumidification, a stream of warm dry air from the desiccant dryer is mixed with the cool moist air from the conventional cooling coil. Properly regulated, the combined air is then within the desired comfort range in terms of temperature and relative humidity. Desiccants dry air by condensation and adsorption. In the process of adsorption the latent heat is converted into sensible heat, converting warm moist air to hot dry air. Desiccant dryers generally use solid-desiccant rotating wheel heat exchangers. Silica gel is the main solid desiccant material. Condenser heat, natural gas, solar or other heat sources can be used to regenerate the desiccants. Such a system is often used as a central fresh air unit instead of a low SHR DX system. The installed cost of desiccant dehumidification equipment is approximately $1,400 per ton (R.S. Means, 1992) or $10 per cfm based on a change in outside air enthalpy of 20 Btu/lb. Other than cost, the extensive maintenance requirements and high regenerative energy and added cooling energy expense for desiccant dehumidifiers may make them a poor choice for use with educational facilities.

Total Energy Recovery System (TERS): A variation on desiccant dehumidification system is the TERS or enthalpy recovery system. The TERS consists of an air-to-air heat exchanger with a rotating-wheel heat exchanger assembly (Figure 33). The wheel is coated with a molecular sieve desiccant coating to provide both sensible and latent heat recovery. The desiccants remove moisture from the supply air stream while also cooling the incoming air with the exhaust air stream. The increased outdoor supply air is matched by a nearly similar level of exhaust air. Generally, the supply air from the desiccant wheel is further conditioned with additional DX or chilled water coils prior to being added to the interior space.

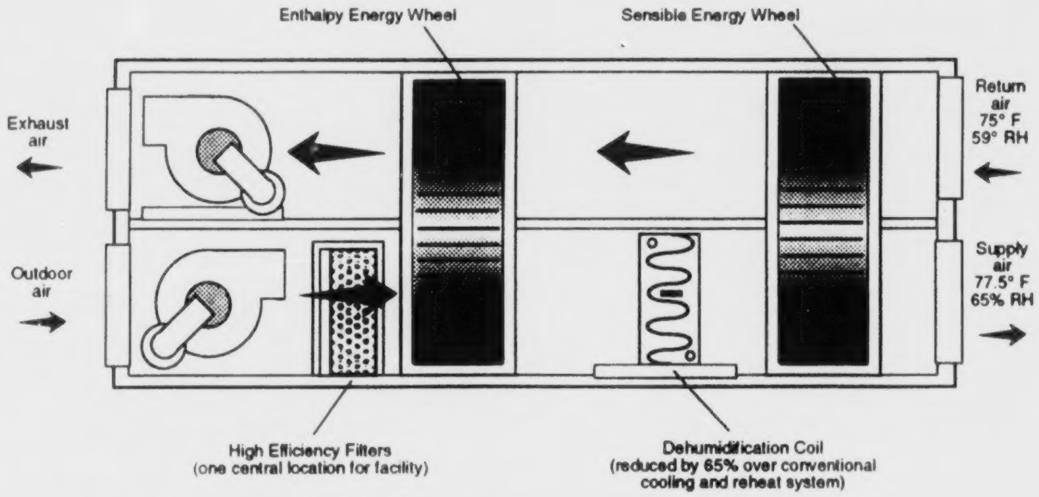
Enthalpy Energy Wheel
Sensible Energy Wheel
Exhaust air
Return air 75° F 59° RH
Outdoor air
Supply air 77.5° F 65% RH
High Efficiency Filters (one central location for facility)
Dehumidification Coil (reduced by 65% over conventional cooling and reheat system)

Figure 33. Total energy recovery system.

A TERS has the significant advantage of producing real energy savings through the transfer of sensible and latent heat between the exhaust and supply air streams. A realistic heat recovery rate is approximately 50%-75% for both sensible and latent heat depending on the target space temperature and relative humidity. The cost is approximately $400-$1,000/ton installed. TERS is mainly applicable for new buildings. Retrofit may be difficult due to required ducting. Maintenance costs are also likely to be elevated, a fact that should be considered in specifying such systems.

Run Around Coils: Another variation on the heat pipe is the use of "run around coils," usually containing a water-glycol mixture with finned heat exchangers to transfer heat from the return side of the cooling coil to the supply air and thus avoid the need for reheat. Run around coils have the advantage of being more easily retrofit onto existing systems where there may be a fairly large separation between the return and supply air sides of the cooling system. However, unlike passive heat pipes (described below), this configuration require some pumping energy to move the liquid from one coil to the other. Another limitation, similar to that of heat pipes, is that although run-around coils enhance dehumidification under full load conditions, they do not provide improvement to systems with no part load performance.

Heat Pipe Dehumidification: Heat pipes offer an attractive alternative to reheat with other heat sources while greatly increasing the moisture removal capacity of conventional DX and chilled water systems. Unlike, TERS, heat pipes *can not* reduce the cooling load, but only serve to increase the dehumidification potential. A heat pipe is a refrigerant-charged device with a heat exchanger at either end. One end of the coil removes heat from the incoming air stream as the refrigerant in that end is evaporated (Figure 34). The conventional cooling coil (containing chilled water or the DX evaporator) then has less sensible-cooling load and runs colder, removing more moisture from the pre-cooled air. The heat pipe refrigerant gas then migrates freely to the other end of the coil where it condenses, giving up heat. The condensed refrigerant then passively returns to the evaporator section by gravity or capillary action. The bypassed heat is transported by the heat pipe, condensing at its other end and reheating the chilled air without requiring any additional energy. Because the refrigerant in the heat pipe flows passively in a loop between the pre-cooler coil and the reheater coil, it requires no external power and has no moving parts. The added cost of heat pipe dehumidification equipment is approxi-mately $400 per installed ton of cooling capacity, but provides (Dinh, 1992) no reduction in energy use. Heat pipes become less effective as the approach temperature decreases and may not provide adequate reheat during part load operation.

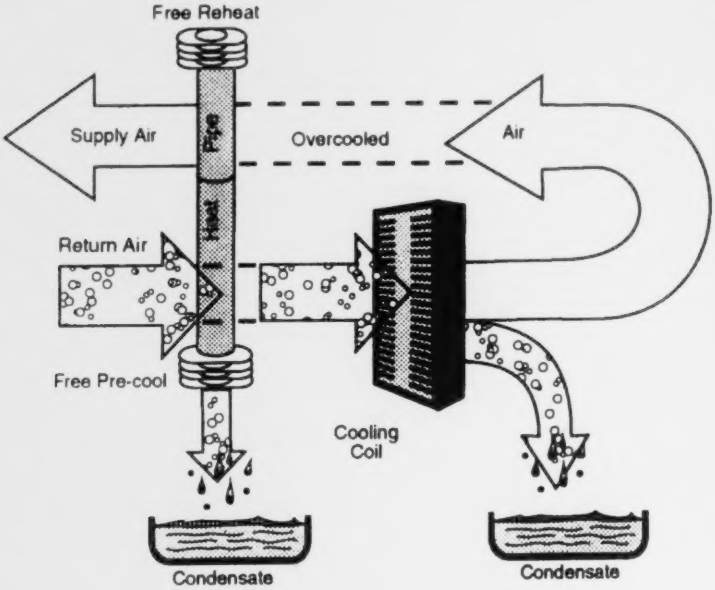

Figure 34.

Face and Bypass Dampers: Facilities using chilled water and constant volume systems can provide face and bypass dampers to reduce the need for reheat while providing effective humidity control. With such a configuration air dampers channel a portion of the return air (which would normally pass through the cooling coil) around the coiling coil (Figure 35). This results in a suitably high supply air temperature along with effective dehumidification. The system uses a draw-through air handling unit to take advantage of the fan heat as added reheat. A mixing box is used to add building air for ventilation and room pressure control. The face and bypass section has cross-linked dampers that give it the ability to pass all the air through the coil or divert any needed amount around the unit. The air passage around the coil is engineered to have the same pressure drop as the coil so the total discharge air volume does not change. When dehumidification is needed the coiling coil temperature is lowered to remove additional moisture; a portion of the entering air bypasses the cooling coil to hold the discharge temperature needed to maintain the required room temperature. The result is improved temperature and humidity conditions with less need for reheat.

Monitoring of face and bypass controlled chilled water systems in schools shows that classroom humdities can generally be controlled to around 60% RH except during low-load periods when supplemental supply air reheat will be necessary to avoid higher humidity levels. Low loads also prevail during after-hours operation when face and bypass control can lead to high moisture conditions under constant fan operation. However, through the use of CO_2 sensors with an energy management system, face and bypass dampers can control the humidity below 50% without reheat, by changing the routine to *fan cycling* during after hours periods.

One improvement on the overall concept is to use *dual* face and bypass dampers, one controlling the space return air and the other to pre-conditioning the outside air. This provides better control under low load conditions. By controlling the outside air with face and bypass dampers as the first stage ofthe system, better control of interior humidity should be possible with the need for reheat obviated except during the most adverse part-load conditions.

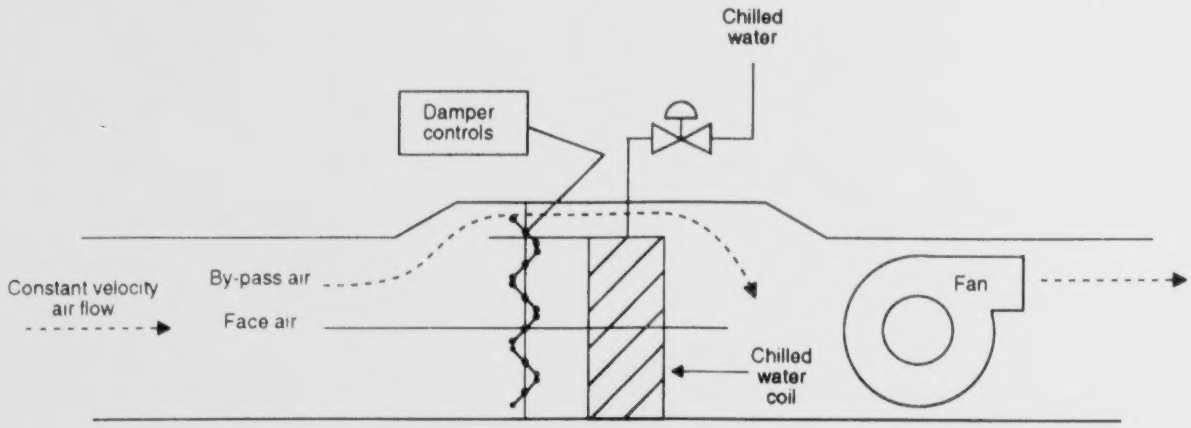

Figure 35.

b. Ventilation To Offset Cooling Requirements

Natural Ventilation: Natural ventilation was commonplace in Florida schools in the 1950s prior to the advent of mechanical air conditioning. It has become less common in recent times. However, natural ventilation is an option to mechanical air conditioning as per the Florida Code. Detailed guidelines have been developed showing how educational facilities can be naturally ventilated (Chandra, 1985). However, if the building is mechanically conditioned there is no specific requirement for natural ventilation. Whether natural ventilation is advisable in mechanically conditioned educational facilities is a subject of debate. Generally, the high humidity levels in Florida's outdoor environment serves to exact very stringent limits on the utility of natural ventilation if interior moisture levels are of concern.

For this project, FSEC staff conducted an analysis using Typical Meteorological Year (TMY) data to examine when natural ventilation might be useful to offset mechanical cooling. We examined the weather data for Orlando from September to May between 8 AM and 4 PM to establish the number of hours when ventilation might be feasible for educational facilities. Of the 2,184 hours during this period, some 906 hours (41% of the time) had an outside air temperature less than 72°F -- a seemingly promising value. However, if outside relative humidity is considered, there are only 408 hours (19% of the time) when the temperature is less than 72°F and the outside humidity is less than 65%. Realistically, a classroom environment with its heavy internal heat production will require outside air at 68°F or below to produce feasible natural cooling. Disregarding humidity, we found 29% of hours were below 68°F, while only 12% of total hours were below 68°F and had outside relative humidity less than 65%. Moreover, although these values would seem to suggest that 12 - 19% of the air conditioning season might be eliminated by natural ventilation, a much smaller fraction of the overall space cooling energy would be eliminated, since the hours when ventilation is feasible are precisely those times when building loads are low and cooling system efficiency is highest.

Although not attractive as the main building cooling system, the capability of having operable windows for natural ventilation does have other potentially important justifications. In some circumstances it may be very desirable to extensively ventilate a space. Such situations include the need to fully ventilate during cleaning or painting operations or other times when a complete purge of the room air is needed. Also, the availability of operable windows does provide some cooling and ventilation during times when the space conditioning system is inoperable or in the process of undergoing repair or replacement. Against these advantages, however, a facilities planner must weigh the increased first cost of operable windows as well as minimizing potential for vandalism or unauthorized access.

Economizer Cycles: An economizer cycle is a mechanical version of natural ventilation and can be used with single and dual duct ventilation systems. Economizers consist of three sets of dampers with linked controls. An exhaust damper relieves system return air to offset ventilation air brought in. An outside air damper controls the quantity of ventilation air brought into the system, and a return damper balances the return and outside air portions of the economizer. At low temperatures (below 60°F) the economizer dampers adjust to the minimum ventilation setting. This reduces the cooling load while providing necessary ventilation air. At high ambient temperatures (above 68°F) the dampers return to this minimum position to provide for ventilation requirements. Between these temperatures the economizer dampers modulate from minimum ventilation air to 100% outside air to meet cooling requirements. Integrated economizers allow simultaneous economizer and mechanical cooling; non-integrated economizers do not.

Economizers can be set to operate solely based on outside temperature (operate when the temperature of the outside air is below the temperature of the return air). Enthalpy economizers compare the enthalpy of the outside air and the return air stream to determine which air has the lower heat content. Enthalpy economizers should always be specified if considered in Florida's humid climate. We simulated the economizer cycle to be activated at a time when the temperature fell below 68°F and relative humidity was lower than 55% (internal latent heat gain would drive space levels to approximately 60%). Unfortunately, the same limitations which exist for natural ventilation also hold true for the economizer cycle. Generally, the humidity is too high and hours within acceptable temperature limits too short for such systems to be cost effective in Florida's conditions.

Ceiling Fans: The use of ceiling fans to provide air motion and improve comfort and allow higher thermostat set-point is well established. Research suggests that air motion permits comfort at temperatures from 2 - 6 °F higher than would be possible without ceiling fans. For our analysis we chose conservative assumptions. We assumed that use of ceiling fans would allow a 2°F increase in the thermostat setting in educational facilities. However, we also increased the building equipment loads to reflect a 40-watt average electricity use for each fan. Ceiling fans were analyzed as an option for the classroom and administrative buildings. Their use was found unpractical in the multi-use facility. Our analysis found moderate savings in the administrative facility, but very substantial savings potential in the classroom building. Regardless of these results, we do not necessarily endorse the use of ceiling fans in Florida educational facilities since fans may create problems: the effects of air motion on papers, and the potential distraction from moving shadows caused by fan blades moving below recessed ceiling luminaires. There have even been reports of students experiencing motion sickness from the strobing effect of the fan blades across the lighting fixtures. There are also concerns associated with vandalism.

Furthermore, for the savings to be realized, the thermostat must be set higher. Since the occupants often do not control the air temperature setting, the theoretically available savings may

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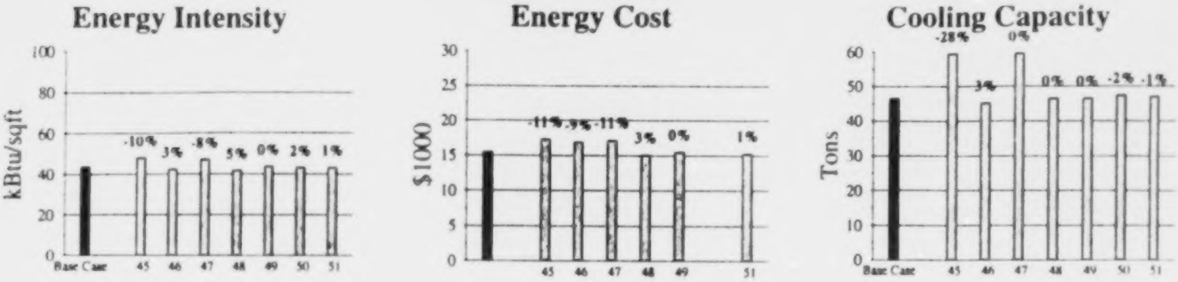
Energy Intensity

Energy Cost

Cooling Capacity

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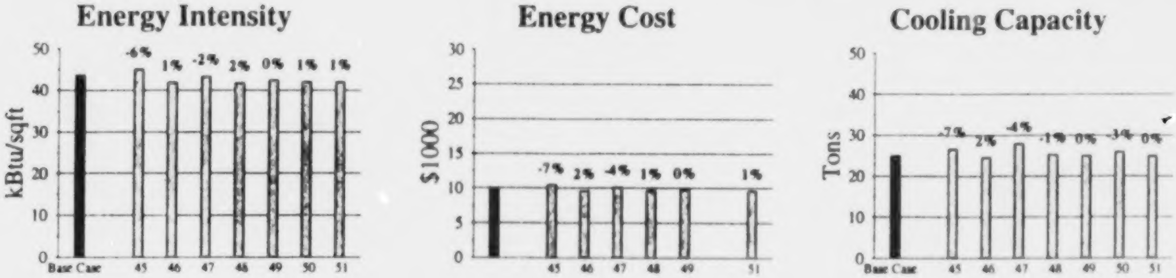
Energy Intensity

Energy Cost

Cooling Capacity

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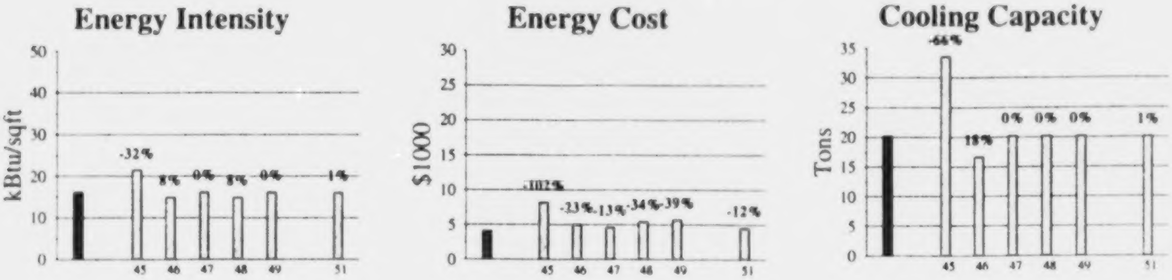
Energy Intensity

Energy Cost

Cooling Capacity

45	15 CFM per Person	49	Enthalpy Economizer
46	TERS 5 CFM per Person	50	Economizer Cycle
47	TERS 15 CFM per Person (compared to #45)	51	Reheat Constant Volume
48	Energy Management System		

Figure 36. Ventilation and dehumidification options.

not be achieved. It is noteworthy, however, that project staff members have observed ceiling fans in use in some older Florida schools. It is thus possible that ceiling fans may be appropriate in some situations.

4. Cooling Systems

a. Central Chillers

Central chilled water systems are generally larger than standard split or packaged DX systems and may be used to provide cooling for a large educational facility. These systems typically consist of a central reciprocating, centrifugal scroll or screw chiller to cool water which is then distributed by the appropriate fan coil or air handling system. Chiller efficiency is often rated at kW/ton of cooling at standard conditions (evaporator=40°F, condenser=105°F, suction gas =55°F, no sub-cooling). Most schools will need chillers in the 50 - 300 ton range depending on facility size and characteristics. In choosing a chiller, select a unit with the best cooling efficiency and lowest life cycle cost. This is often given in kW/ton of cooling or alternately as cooling Coefficient of Performance (COP), (IPLV), or Energy Efficiency Ratio (EER). Look for chillers with the lowest kW/ton and conversely with the highest COPs, IPLVs, and EERs.[6] Particularly, when considering larger equipment, consider the part-load performance of cooling systems, since the facility will seldom be operating under full load conditions.

Reciprocating Chillers: Reciprocating compressors compress refrigerant using pistons that are driven directly through a connecting rod from the drive crankshaft. This is the default chiller type used in the simulations. There are two main types: open and hermetic reciprocating chillers. In hermetic systems, the electric motor and compressor encapsulated in the refrigerant stream, whereas the motor is external in the open-drive configuration. The open-drive types are generally preferred due to their greater efficiency since the motor heat is not released into the refrigerant loop. One advantage to reciprocating chillers is that they are available in small sizes. Open-drive types are also amenable to use of gas or diesel powered engines to drive the compressors. Reciprocating chiller sizes vary from 5 tons to over 300 tons. Reciprocating chillers generally have lower efficiency than most other types. In these sizes a typical reciprocating chiller would have an efficiency of approximately 0.90 kW/ton or a COP of approximately 3.8 (ASHRAE, 1991). They are also noisy and cause vibration. Consider scroll compressors as an alternative.

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[6] A chiller with a performance of 0.8 kW/ton would indicate an EER of 15.0 Btu/W (1/8 • 12,000 Btu / 3,413 Btu) and a COP of 4.4 (15.0/3.413 Btu/W)

Centrifugal Chillers: Centrifugal chillers are a common larger chiller type. They often have very high efficiencies (COP ~ 5.0) but generally have lower part-load efficiencies. Centrifugal compressors are usually large; sizes typically range from 100 - 11,500 tons. Systems are available in open-drive types which are amenable to use with mechanical drives. Electric, gas or diesel engines may be used to drive such open-drive chillers. The best centrifugal chillers have efficiencies approaching 0.55 kW/ton (COP= 6.4) at full load.

Screw Chiller: Helical rotary or screw chillers generally have a slightly lower efficiency (COP ~5) compared with centrifugal chillers, but have a higher part-load efficiency at low cooling load ratios. They are also available in smaller sizes from approximately 75 tons to 750 tons. The best helical rotary chillers have efficiencies approaching 0.60 kW/ton (COP = 5.9). Due to their excellent part-load performance, screw compressors are often configured in pairs with each unit able to meet the building load under full-load conditions. Units are then operated in a staged fashion, either singly or in combination so that they operate near optimum part-load efficiency. Such a configuration also imparts greater redundancy to the central chiller system since a single chiller can meet load while the other unit is serviced. Screw chillers are characteristically noisy and require acoustical isolation from occupied spaces and surrounding neighborhoods.

Absorption System: This is a special case where most of the cooling energy is really provided by the heating plant. Unlike an electric chiller, a chemical process is used to vaporize and condense the refrigerant. Thermal energy from a gas burner is used in the generator where high-pressure refrigerant is liberated from the absorber (Figure 37). The high-pressure refrigerant is then cooled and condensed in the condenser, where the heat is rejected to a cooling tower. The condensed refrigerant passes to the evaporator, where the concentrated absorbent causes some of the refrigerant to evaporate which in turn cools the chilled water in the evaporator coil. The efficiency of absorption systems is fairly low, although the fact that they use a low-cost source of energy may make them competitive. For instance, an absorption chiller will generally use 60% more source energy than a centrifugal chiller. Absorption chillers are water-cooled, typically using a lithium bromide/water or water/ammonia cycle. They are available in several sub-types, although direct-fired systems are most popular. They are more compact that conventional chillers, have few moving parts and produce less noise than conventional systems. Absorption systems should be considered for large central cooling systems where there is a large difference between the applicable price for natural gas and electricity.

Gas-powered Chillers: Natural gas-powered engines can be used as the drive for various type of open reciprocating, centrifugal and screw chillers. According to the ASHRAE Systems Handbook, the specific gas consumption for natural gas engines is from 8 - 13 cubic feet of natural gas per horsepower hour (ASHRAE, 1992). Since one horsepower equals 0.746 kW, such engines will use 6 - 10 cubic feet per kW of input power to chillers. The natural gas consumption per ton of cooling can then be estimated by knowledge of the specific chiller performance. For instance, a gas engine driving a screw chiller producing 0.70 kW/ton of cooling would require 4.2 to 7 cubic feet of gas to produce a ton of cooling depending on the engine characteristics. It should be noted, however, that the performance efficiency curve for gas-driven engines is fairly flat

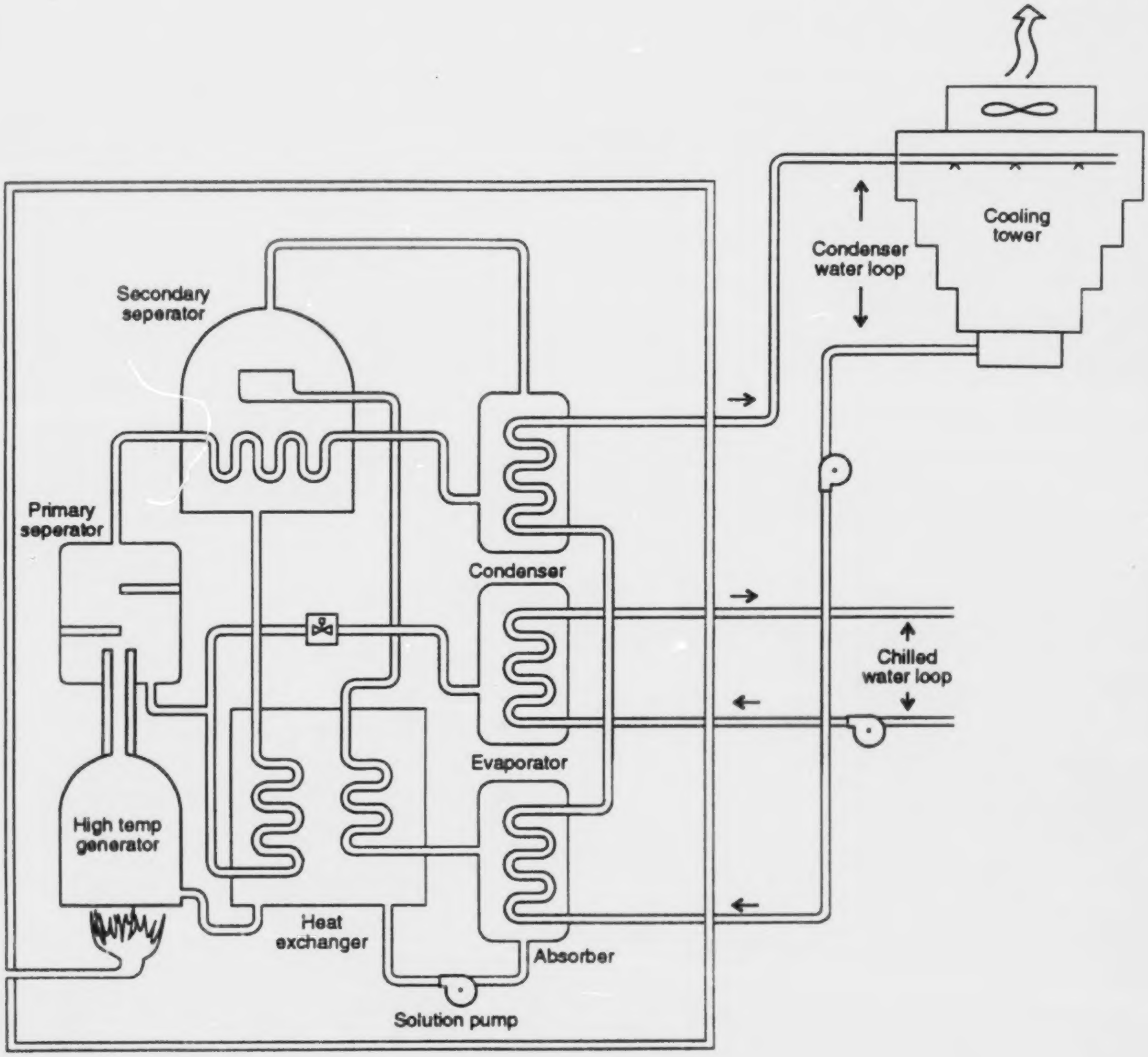
Cooling tower
Condenser water loop
Secondary seperator
Primary seperator
Condenser
Chilled water loop
Evaporator
High temp generator
Heat exchanger
Absorber
Solution pump

Figure 37. Gas fired absorption chiller.

down to approximately 40% of the design capacity. Below this point, the efficiency drops off sharply where cylinders are unloaded to further reduce capacity below idle speed. Also, first cost and maintenance of natural gas-fired engines are both generally greater than with electrical drives.

b. Condensing Systems

Cooling Towers: With cooling towers, water is cooled by contact with the air to reject heat from the water-cooled condensers of the air-conditioning systems. Either natural draft or mechanical draft systems perform the cooling. Mechanical draft towers are most common because they do not depend on wind to function properly. Towers are usually specified in multiples to provide redundancy, ease of maintenance and the capability to be run at reduced capacity where their efficiency is highest. If considering a central chilled water system that will use a cooling tower, the designer should ask project engineers for an incremental analysis of the efficiency improvements available from increasing the size of the projected cooling tower. Increasing the cooling tower size will reduce heat exchanger approach temperatures and improve chiller system efficiency.

Air Cooled Condensers: Air-cooled condensers pass outdoor air over a dry coil to condense the refrigerant. This results in a higher condensing temperature and lower performance under peak conditions. It is preferred, however, for packaged systems and unitary heat pumps due to its simplicity and low maintenance requirements. It should be avoided with larger central chilled water systems since chiller efficiency is impaired.

Evaporative Condensers: Evaporative condensers pass air over coils sprayed with water taking advantage of the latent heat of vaporization to reduce the condenser temperature. These condensing systems are the most efficient, although such systems increase water use and have extensive maintenance requirements. As with, water cooled cooling towers, these systems must have freeze protection and close control of

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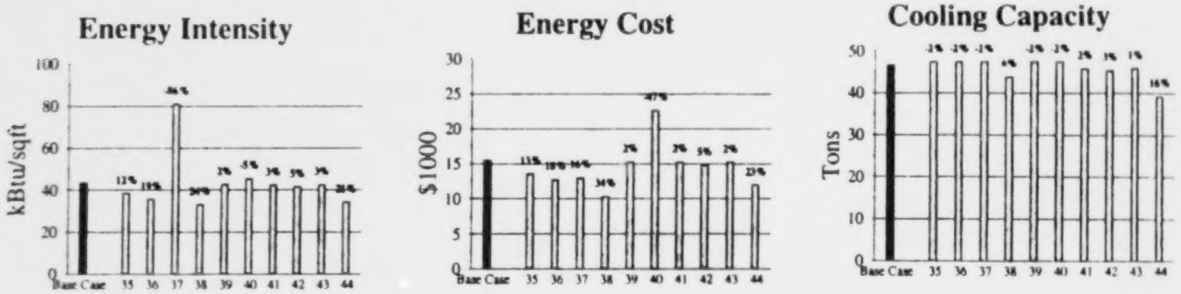

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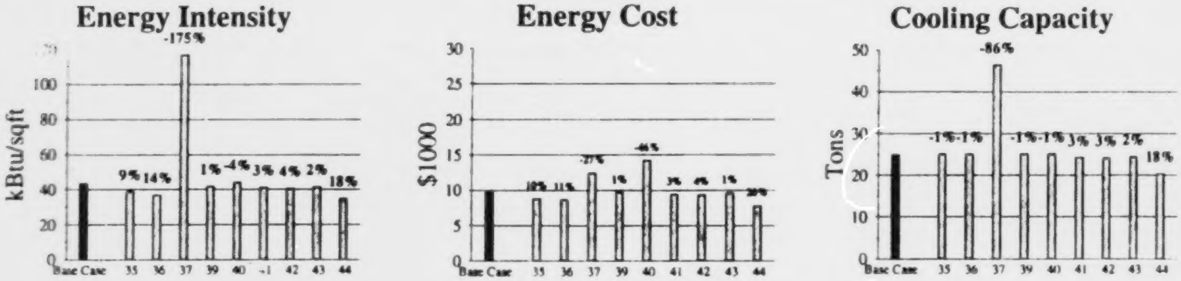

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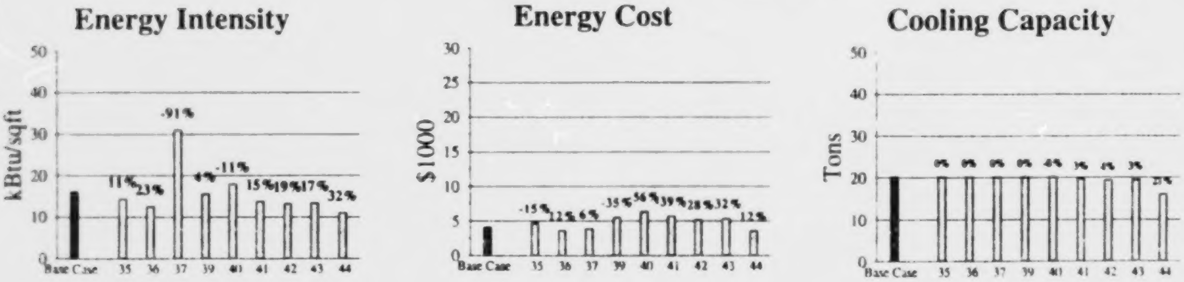

35	Centrifugal Chiller	40	Non-Variable Speed Fans
36	Screw Chiller	41	Variable Temperature Constant Volume
37	Gas Absorption Chiller	42	Multizone Constant Volume
38	Ceiling Fans	43	Dual Duct Constant Volume or Variable Volum
39	Variable Speed Pumps	44	Four Pipe Fan Coil

Figure 38. Chiller and air distribution options.

water treatment to function successfully. However, because of their greater efficiency, projects should consider their use.

c. Packaged Terminal Air Conditioners

A packaged terminal air conditioning (PTAC) system is a combination of a cooling unit (using air-cooled direct expansion with integral compressor, evaporator and condenser), an optional heating unit (usually electric resistance or "strip heat") and an optional minimum ventilation intake. Zone temperature is controlled by off-cycling of the unit. Packaged heat pumps are also used, and are generally identical to the PTACs although with greater heating energy efficiency. Such packaged systems are very popular in older Florida schools and for cooling manufactured classroom buildings (portables). However, they offer unacceptable humidity control at a ventilation rate of 15 cfm/person if fans are run continuously while the compressor cycles. If specified, higher efficiency units (SEER, EER) should be chosen while selecting the lowest SHR (sensible heat ratios) possible.

If multiple units are used to serve a space, their operation should be staged to provide better humidity control. In general, PTACs, unitary heat pumps, and roof-top units will not provide sufficient moisture removal to achieve humidities less than 60% even at 5 cfm per person. *FSEC and engineering firms in Florida have often seen that packaged AC systems are significantly oversized for the sensible loads in Florida educational facilities. Along with their poor part load performance, such oversizing has grave consequences for effective humidity removal. In general, units should never be sized larger than that indicated by approved sizing methods.*

d. Unitary Heat Pump

Multiple packaged unit heat pumps have been popular in Florida schools. Each packaged heat pump has a self-contained direct-expansion cooling system, an outside condenser, and associated controls (Figure 39). They have the advantages of being relatively low cost, modular in installation, with simple controls and maintenance. On the other hand, unitary heat pumps are not generally as efficient as central chiller systems with VAV air distribution. However, they will often be *more* efficient than constant-volume systems, with smaller inefficient reciprocating compressors. They also do not readily lend themselves to humidity control, and operating sound levels may be high. More specifically, these units will not control humidity if the fan remains on while the compressor cycles. A variation on the packaged system is the split

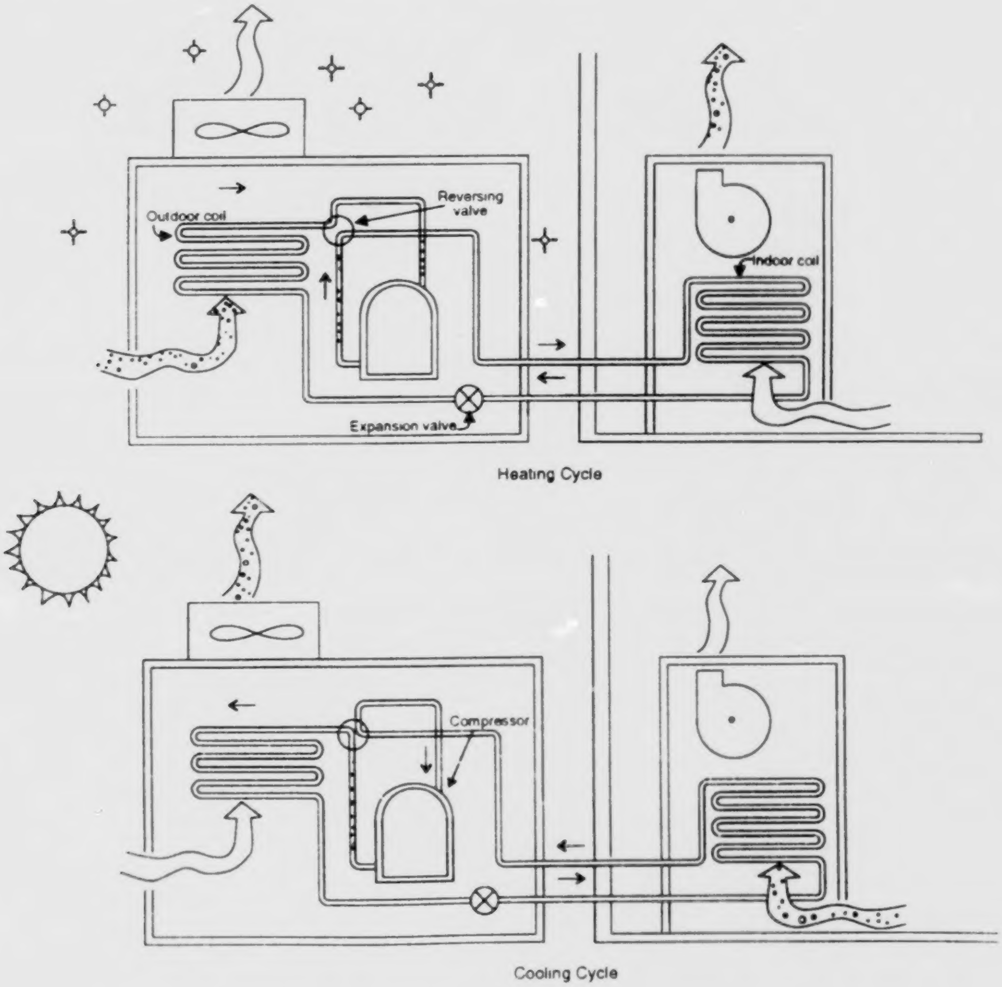
Outdoor coil
Reversing valve
Indoor coil
Expansion valve
Heating Cycle
Compressor
Cooling Cycle

Figure 39. Heat pump in heating mode (top) and cooling mode (bottom).

direct-expansion system where the evaporator and condenser components are separated. Otherwise, performance and other considerations are very similar to the packaged heat pump. There is some latitude, however, in specification of specific fan coil units for match with given condensing units. In any case it is important the equipment not be oversized since effective humidity removal with such system will critically depend on extended run-time fraction. Also, when several through-the-wall packaged units are used for a building, it is preferable to run the fewest units that will satisfy the building load rather than to run all units. Running all units in an unstaged fashion will lead to short-duty cycles, lower efficiency and ineffective humidity removal. Generally, equipment should be chosen with the greatest seasonal energy-efficiency-ratio (EER) for cooling and heating season performance factor (HSPF) for heating. SEERs should be greater than 10.0 Btu/W; HSPF should be greater than 7.0 Btu/W. For a given efficiency, choose a unit with the lowest sensible heat ratio (SHR) to provide better humidity removal.

e. Incremental Heat Pump

This system consists of water-to-air heat pumps in each zone interconnected by a water loop, which is sometimes in line with a large storage tank (Figure 40). The temperature of the water loop is kept within a limited range by a combination of a cooling tower and a heating plant. The heating plant is usually a boiler, though any other heating plant could be used. When all zones require cooling, the heat pumps reject heat to the water loop, which in turn transports the heat to a cooling tower where it is rejected to the atmosphere. Depending on the size of the storage tank and the duration and intensity of the heating demand, the water temperature may drop sufficiently to require heating from the boiler. During intermediate seasons, zones in the heating mode use the heat rejected by other zones in the cooling mode. The specific zone temperature is controlled by the on-off cycling of the unit. Additionally, the water loop can be used to produce reheat when needed.

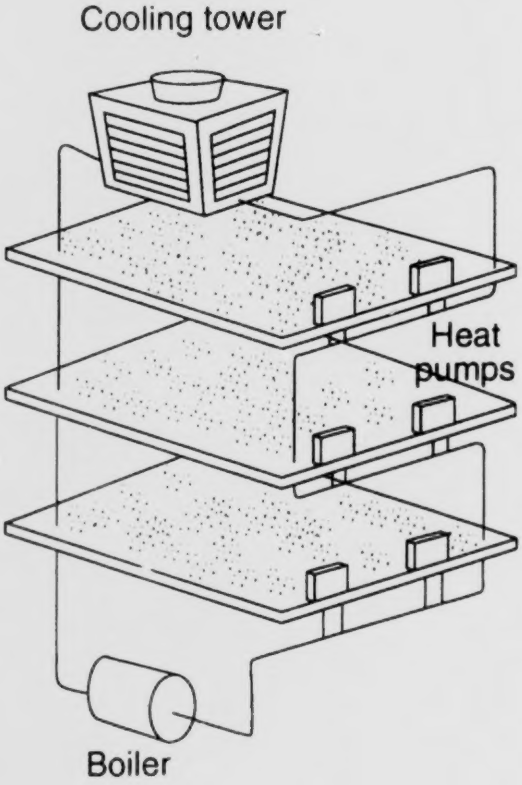

Figure 40. Heat pumps in each space are connected by water loop.

f. Room Air Conditioners

Room air conditioners are packaged systems with a combined compressor, condenser and evaporated all in one unit. These have often been used in older schools or as add-on units to condition individual classrooms. Cooling capacities typically vary from 5,500 Btu/hour all the way up to 20,000 Btu/hour. The units' energy efficiency ratios (EER or Btu/W of input power at the ARI Standard Rating condition) vary considerably from one unit to the next, from 8.0 Btu/W all the way up to 12.6. The "Directory of the Most Efficient Room Air Conditioners for 1994", (FSEC-GP-56-94) is available annually from FSEC. Chosen units should have EERs greater than 10.0 Btu/W. In general, room air conditioners should not be used for educational facilities.

g. Rooftop Units

Roof-top units (RTUs) are a packaged form of a Variable Temperature Constant Volume (VTCV) system. They have been popular with some school boards due to their low expense and the ease with which they can be added to buildings in a modular fashion. However, many school districts prohibit their use due to maintenance issues. Sizes vary from 6 to 20 tons of capacity but their efficiency is often low. Units are commonly rated at their EER at standard conditions. Chosen units should have EERs greater than 9.5 Btu/W with the lowest possible SHRs. A buyer's guide is available from *E-Source* (303-440-8500) that lists the most efficient packaged roof-top systems by their cooling capacity. Dehumidification performance is poor; particularly under part load conditions. However, to enhance moisture removal, these units should have dual split-row coils with the lead coil on bottom for part-load dehumidification.

5. Air Distribution Systems

Although there are numerous variations, there are two primary types of air distribution systems for non-packaged units: constant air volume distribution systems and variable air volume systems. Within these types, single-duct systems tend to be less costly and less expensive than dual-duct and multizone systems, but reheat is generally required. VAV systems are generally more efficient.

a. Constant Air Volume Systems

A Constant Volume Terminal Reheat (CVTR) system cools a constant flow of mixed air to design minimum cold supply conditions, sometimes modified by an outside air reset or a discriminator. Reheat coils near each zone air diffuser provide zone temperature control. This system is simple and inexpensive to install but it is expensive to operate due to the excessive cooling of the design and because so much of the heating energy is required for reheating cold supply air. Proper operation of this system requires that heating and cooling equipment be energized simultaneously for all but the most extreme seasons. Generally, out-

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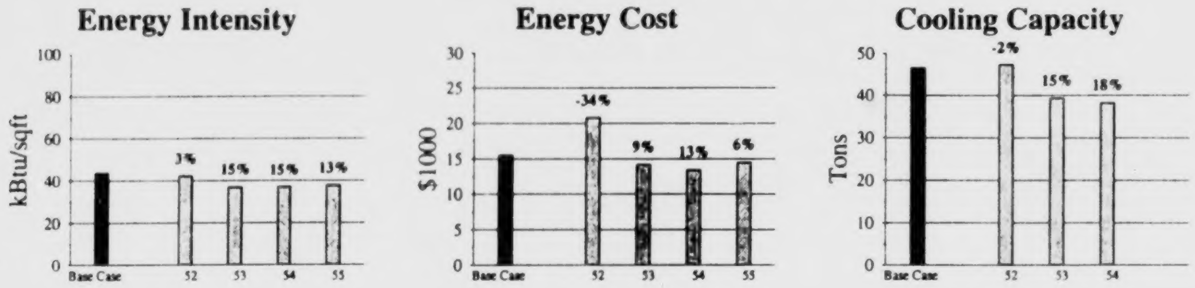

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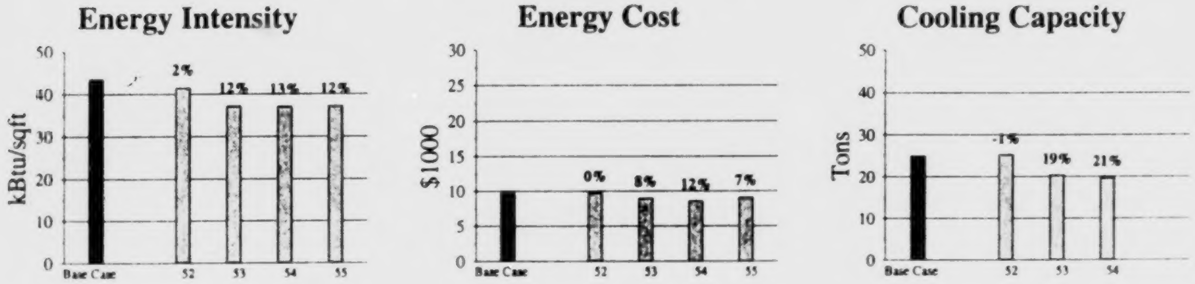

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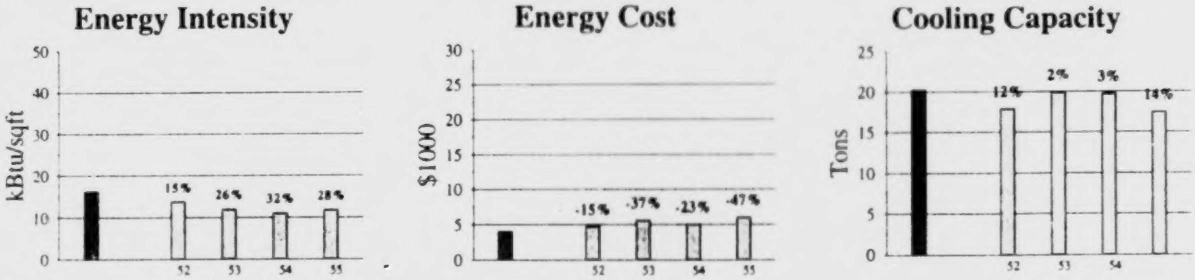

52	Unitary Heat Pumps	54	Packaged Multizone DX Unit
53	Packaged Single Zone Variable Temp DX Unit	55	Packaged Terminal AC / Heat Pump

Figure 41. Packaged HVAC options.

door air reset or dis-criminator control should not be used in Florida's humid conditions.

b. Variable Temperature Constant Volume (VTCV)

The variable Temperature Constant Volume (VTCV) system cools or heats a constant flow of air. Zone temperature control is achieved by modulating cooling or heating coils sequentially (i.e., never at the same time as with a CVTR system). A central forced-air residential system with a gas furnace and a central air conditioner is a very simple version of a VTCV system. However, because it provides only heating or cooling and only at the cumulative rate demanded by all zones, the VTCV system is relatively energy efficient, but provides poor temperature control for individual zones. The return air thermostat of a VTCV system responds only to the aggregate needs of the building. If more zones require heating than cooling, heat is supplied. Dehumidification performance can be very poor; these systems should be avoided in Florida's climate.

c. Variable Air Volume Systems

A Variable Air Volume (VAVS) (Figure 42) controls temperature within a space by varying the quantity of supply air rather than the supply air temperature. However, as the cooling demand in a zone decreases, the air flow to it is reduced to a "minimum fraction" typically on the order of 15 - 30% of the full flow rate. The minimum fraction is generally the lowest acceptable air flow to limit maximum humidity and provide required ventilation air. Reheat occurs only when this point is reached and is generally lower than with single-zone reheat systems. As the heating load increases, the air flow may increase to meet the load. Compared to a terminal reheat system, a VAV system saves energy in three ways: (1) reheat energy consumption is minimized; (2) fan energy consumption is decreased at low volumes; (3) cooling coil consumption decreases significantly as less volume of mixed air must be cooled. Energy is saved with the VAV system by reduced need for simultaneous heating and cooling of spaces as with reheat, as well as reduced fan power. Dampered VAV boxes should be preferred over fan-powered boxes which typically have inefficient motors. One useful case for fan-powered boxes, however, is with a *Power Induction Unit*. A power induction unit is used with a VAV system to keep zone air temperatures at a sufficiently high level without paying the price of higher energy consumption associated with higher air volumes and reheat. As system air volume is decreased to the minimum stop at lower cooling loads, a fan between the VAV box and the zone air inlet (the power induction unit) starts adding return plenum air to the supply air. Heat from light fixtures rejected to the return air plenum is thus recirculated into the zone. Conventional reheat is added only when this recirculated air is inadequate to maintain zone temperature. However, plenum return air systems are very energy inefficient and can lead to conditions that promote air quality problems. They should be avoided in favor of ducted return systems.

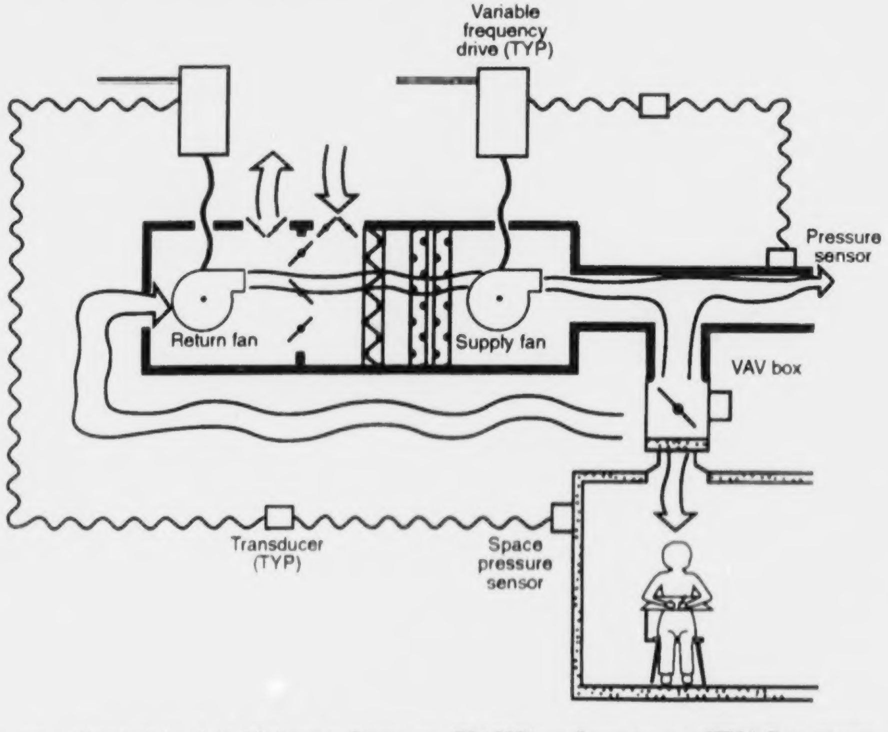

Figure 42. Variable Air Volume System (VAVS) refers to an HVAC system which varies the amount of conditioned air supplied to a zone in accordance with the need in that zone.

There are several potential problems to note, however, with VAV systems:

1. Reduced air flows at lower part loads can provide low air turnover rates and filtration for the space.
2. VAV systems can fail to effectively dehumidify spaces at low part loads. Theoretically, when the students are in the classroom and the system reduces the air flow under low load conditions, the effective air dehumidification is reduced while the latent loads in the room remain fixed. Resetting the supply air temperatures can further aggravate the problem.
3. Fan powered boxes, can lack effective filtration equipment which can load the ductwork downstream with dust and dirt leading to potential IAQ problems.

The fundamental response to these potential problems lies in insuring that the minimum stop ("minimum fraction") for the VAV boxes is no less than the minimum ventilation rate for the space. For classrooms, this can be a much higher level (~50% of the design flow rate) than commonly specified for less densely occupied spaces, such as offices. When lower flows are required to control temperature, reheat coils should then be used to control space conditions (see *Dehumidification Technologies*, page 92).

Effective and efficient filtration equipment is a must for the overall air handling system. In general, fan powered VAV boxes should be avoided, both because of their lack of suitable filtration as well as their added impact on energy use. Obviously, the test and balance of VAV systems to insure adequate air flows and ventilation to building spaces is vital to successful performance.

Also, with VAV systems, proper specification of air diffusers is vital to avoid "dead zones" from poor air circulation in rooms. In constant volume and particularly in VAV systems, it is critical to specify louvered type ceiling diffusers or sidewall grilles that meet the ASHRAE recommended throw ratios at design conditions. These types of diffusers offer excellent part load throws that maintain good air motion. Do not oversize air devices in VAV systems. If oversized, they will operate at lower than design airflows during most periods.

d. Low Temperature Air Systems

A recent development for air distribution systems is the use of low-temperature air. Instead of 55°F air, air at a temperature of approximately 40°F is circulated in the system. The low-temperature air system allows the use of considerably smaller duct work in air handlers. Chiller efficiency may be somewhat reduced due to the low operating temperature of the water-glycol solution, however, such systems require less fan power and provide enhanced dehumidification due to the low evaporator or chilled water temperatures involved. Low-temperature air systems are often used in concert with thermal storage systems, but can be utilized in conventional configurations. First costs are substantially reduced because of the lower expense of the smaller motors, fans and duct work. However, high-induction air diffusers and well insulated ducts are necessary with low-temperature air systems to ensure that diffuser condensation and localized overcooling does not become a problem.

From a practical stand point low temperature air systems may be viable for administrative and library buildings. However, at 15 cfm per student, low temperature air becomes a less viable alternative for classroom buildings due to the high concentration of occupants. Typically, classroom spaces have about 30 occupants and require between 900 and 1200 cfm of 55° air for cooling. At the new ventilation rates, the space would require 450 cfm of outside air which is between 40 and 50% of the total cooling supply air at 55°F. If the supply air were reduced to 40°F, the typical classroom air volume would be between 514 cfm and 685 cfm while the ventilation airflow would remain at 450 cfm, or between 66 and 88% of the total airflow. Cooling humid outside air to these low temperatures may be impractical from a energy and operational standpoint.

However, the described limitation is obviously affected by the required ventilation rate as well as the potential to reduce the fraction of outside air to total airflow through the use of a central fresh air unit for the overall facility.

e. Dual-Duct Systems

Single-duct systems are typically more energy efficient. The dual-duct and multizone systems described below should be generally avoided:

Dual-Duct and Multizone System: The Dual Duct System (DDS) has central supply and return fans and two sets of ducts, one with a cooling coil, the cold deck, and the other with a heating coil, the hot deck. Mixing boxes are located in each zone for supply air temperature control while the flow of air to each zone is fixed. At maximum cooling demand, only air from the cold deck is supplied to the zone. As cooling demand drops, more air from the hot deck is added. Similarly, during peak heating needs, only air from the hot deck is added. The Multizone (MTZ) system is identical to the Dual Duct System except that the mixing boxes are located at the central air handling unit with only one duct per zone to carry supply air. The hot deck can carry preconditioned ventilation air at a constant supply flow. Ventilation air temperature can then be modulated to maintain the temperature in the most critical space.

Dual-Duct Variable Air Volume: A Dual-Duct Variable Air Volume (DDVAV) system can be thought of as a dual-duct system with variable volume central fans and variable volume mixing boxes at each zone. At maximum cooling demand the DDVAV system supplies the maximum volume of cold air to the zone. As cooling demand diminishes, this volume is reduced until reaching the "minimum stop." As the zone begins to need heating, the hot deck starts supplying air volumes at gradually increasing rates up to the maximum design air volume.

f. Duct Energy Losses

Energy waste due to air leakage in duct work and terminal devices can be considerable. All air handling systems and associated duct work should be carefully sealed. ASHRAE (1991) estimates that ductwork installed in many commercial buildings can have leakage rates of 20% or more. Projects should strive to:

- Ensure that all system air handling equipment and duct work is located within the insulated building envelope.
- Specify in the project construction specifications that the duct work for the building be commissioned prior to occupancy and pressure tested to yield air leakage no greater than 30 cfm at 50 Pa pressure per 1,000 square feet of conditioned floor area.

g. Air-and-Water Systems

Fan Coil Systems: Fan coil (FC) systems consist of zonal fan units connected by one or two water loops with circulation pumps to a central cooling and heating plant. Optionally, fan coil units can provide minimum outside air for ventilation, but are not particularly appropriate in humid conditions. Two-pipe FC units can provide heating or cooling through the same pair of pipes, but not at the same time. The change from the heating to the cooling mode is made seasonally. These two-pipe units are not recommended for Florida's climate. A four-pipe FC unit can provide heating and cooling simultaneously. Each individual zone can be either in heating or cooling mode, but not both. Neighboring zones may be in a different mode, however. Although initially expensive, fan coil systems provide high performance levels since the water loops more effectively transfer heat than air. Also, pumping power requirements for the working fluid is generally lower than that for the fans in air handling systems. However, the zone-located fan coil units also tend to have greater operating sound levels than conventional air systems; this should be carefully evaluated for the specific application. Additionally, when these units need service, maintenance personnel may have to disrupt class or work time. *As with packaged systems, proper sizing (never oversized) is critical to the dehumidification performance of fan coil systems.*

There are two basic types of control used with fan coil systems:

1. Modulating fan coil: The chilled water flow is throttled depending on the space cooling needs. However, at a reduction of 40% of the water flow, some 55% of the dehumidification potential at full flow is lost. Even small reductions to chilled water flow can severely reduce humidity removal potential.

2. On/Off coil: The coil operates like a standard PTAC air conditioner. The coil is only powered when the thermostat calls for cooling. However, again, under part load conditions the the effective moisture removal of the system will be degraded due to the pronounced off-cycle times.

Small fan coil units seldom have sufficient latent capacity to handle the high latent conditions in classrooms. Classroom unit ventilators, a higher quality form of fan coil, have an option for face and bypass control which does provide more effective humidity removal. However, all such fan coil systems, should be used only with dedicated outside air systems that precondition 100% of ventilation air.

6. Fan Drives and Controls

Variable speed drives can provide important efficiency improvements to variable air volume systems by varying fan motor speeds rather than using variable inlet vanes or inlet cones with constant speed systems to modulate delivered air volume. Variable speed fan motors are inverter-controlled so that fan speed is adjusted dynamically as VAV boxes call for changing air volume. Variable speed fan drives have the added advantage of limiting the current inrush for the start-up of large motors ("soft start" feature). Variable speed drives for VAV systems save energy and should be specified with such systems. In choosing variable speed fan drives, the designer should be aware that such inverter-controlled devices can introduce undesirable harmonics in the power supply. The designer should work with the drive manufacturer to ensure that such problems are minimized. The cost effectiveness of variable frequency (VF) drives vary with motor size and conditioning system use schedules. Generally, it is cost-effective to use VF drives for motors of 20 hp or more and inlet vanes for smaller units. Keep in mind that inlet vanes increase fan power by 5% simply due to their presence.

7. Energy Management Systems and Controls

Optimal start is an option available with most energy management systems (EMS). At the beginning of the day, the energy management system determines the time at which the cooling or heating system should be activated to bring the building to comfort conditions by the time it is occupied. The time that chiller, boilers and fans are activated is based on a calculation within the EMS based on outside and inside temperatures and historic data (which the EMS accumulates) to determine the best time to activate the conditioning system. Several indoor and outdoor sensors are used. Optimal start saves energy by reducing the system operation to the minimum time necessary to provide comfort conditions. More sophisticated systems allow the building to remain below the heating set-point in the morning hours if it is anticipated that the building will soon need cooling by mid-day. Our analysis generally showed optimum start to be a desirable design feature for Florida educational facilities. Most new educational facilities will have an energy management system. Specification of an EMS with optimal start capability is desirable since paybacks should be very short.

Limited temperature controls should be provided for classrooms. Activity levels in the classroom, particularly for elementary schools, vary to the extent that some level of individual control is desireable. In addition, students come to class attired differently in the various seasons, requiring different space temperatures for comfort.[7] Thermostats are now available, which give the occupant limited control range, allowing them to raise or lower their space temperature within pre-programmed temperature limits. The psychological effect of providing instructors with some degree of control is of great advantage in reducing comfort complaints. Additionally, computer classrooms, with a high saturation of electronic equipment, will require lower temperatures for effective comfort when the equipment is in use.

Thermostats specified for educational facilities should be of the electronic type. These respond much more rapidly to changes in temperature than the old bi-metallic thermostats and provide finer comfort control with less variation in interior conditions. One common oversight to be avoided: the location of control thermostats should be given careful consideration. In general, the devices should be located on interior walls away from direct air movement from difusers. Since most thermostats operate under PID control, improperly located units may lead to over-controlled short cycling and associated lack of effective dehumidification.

One useful feature for EMS systems in schools is that of a pre-programmed thermostat override. Electronic thermostats are available with an override button on the face plate that allows the occupant to signal the EMS system that a space is occupied and needs conditioning during periods when the space is normally vacant. Thus, a teacher or janitorial staff, staying late can achieve temporary comfort without disabling the EMS's energy saving thermostat set-ups for long-term system operation.

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[7] A reasonable argument can be made that student dress codes should support lighter levels of dress during the warmer seasons to promote higher thermostat set temperatures.

One area that cannot be over emphasized with the EMS is the need to properly set-up and commission the equipment. Improper set-up or specification can lead to a lack of flexibility in control, disabling of valuable functions, under control and excess energy use. EMS functions for humidity control should be carefully tested and commissioned, since this is a common area for problems. The project bid specification should also include provision for the proper training of the maintanence personnel at the facility to insure understanding of the systems and ability to effectively use controls. Unnecessary features should be avoided, with the project mechanical engineer providing input to the level of EMS required for the facility rather than the financially motivated vendors.

8. Variable Speed Pump Drives

Variable speed pump drives can potentially reduce pump motor electricity consumption in large central chilled water systems with four or more cooling coils. This is accomplished by matching pump horsepower output relative to the actual flow requirements. A differential pressure sensor on the VAV chilled water line modulates the pump speed based on the pressure across a valve located two thirds of the distance from the pumps to the furthest coil. The valve includes a bypass line so that as the space loads decrease, the control valves on the coil close. The increasing pressuring across the bypass valve is used to slow the pump speed. The pump flow rates are throttled by varying the pump output with a frequency inverter so that it becomes a variable speed drive. Variable speed pumps can be used only on systems that use two-way control valves. Three way values should be placed at the ends of the system to minimize the time necessary to get chilled water to the active coils. Also, savings potential on systems with supply temperature reset controls is significantly reduced. Both chillers and boilers typically have minimum flow rates which limit the potential minimum turndown of variable speed pumps. Reduction of harmonic line distortion is an issue in choosing variable speed pumps as with all inverter-controlled drives.

9. Consensus Recommendations

Based on FSEC's analysis, the many HVAC options available to schools reduce to a few options which have superior performance. These are:

a. Cooling Systems:

Large facilities: Central chiller for facilities with total loads greater than 100 tons. Screw or centrifugal chillers should be specified with minimum kW/ton. Chiller drives can be electric or natural gas depending on relative price of fuels. Absorption chillers may also be considered based on a similar analysis. The decision between air, water-cooled and evaporative condensers should consider the appropriate trade-offs between first cost and system performance. With water-cooled condensers, cooling tower size should be subjected to a careful analysis. Primary/secondary pumping with variable speed pumps should be specified for chilled water systems.

Small or medium sized facilities: Select high-efficiency packaged or split systems for educational facilities with total loads less than 100 tons. Packaged VAV systems may also be considered. However, pre-treatment and dehumidification of introduced outside air is a necssity with packaged equipment. Select the highest system cooling COP, EER, IPLV, or SEER. For heat sources consider using heat pumps or natural gas with straight cooling systems. Hot-gas bypass should be avoided. Improved dehumidification can be achieved by choosing low SHR (sensible heat ratios) for equipment within a given efficiency level and *never* oversizing packaged or unitary equipment used to serve space conditions.

Air Handling: Variable air volume systems, four-pipe fan coil, or constant volume systems with face and bypass dampers should be specified for projects not using packaged systems. Variable speed fans should be used with VAV systems for larger motors. Outside air should be added to such systems with a central fresh air unit, preferably with heat recovery from the exhaust air stream either using heat pipes or a heat recovery ventilation system. Fan-powered VAV boxes should be avoided. Reheat will be necessary for low load operation. It should be provided by non-electric sources, either natural gas, solar or condenser heat recovery.

Duct systems should be well sealed and pressure tested prior to occupancy. The duct system should be located within the envelope insulation. The use of low-temperature air distribution systems should be considered early in the design process with consideration of feasibility against required ventilation rates. Systems should be controlled by an energy management system (EMS) with optimal start capability. CO_2 sensor ventilation contorl should be considered for intermittantly used facilities. Air handling equipment should be balanced and commissioned prior to acceptance.

b. Ventilation

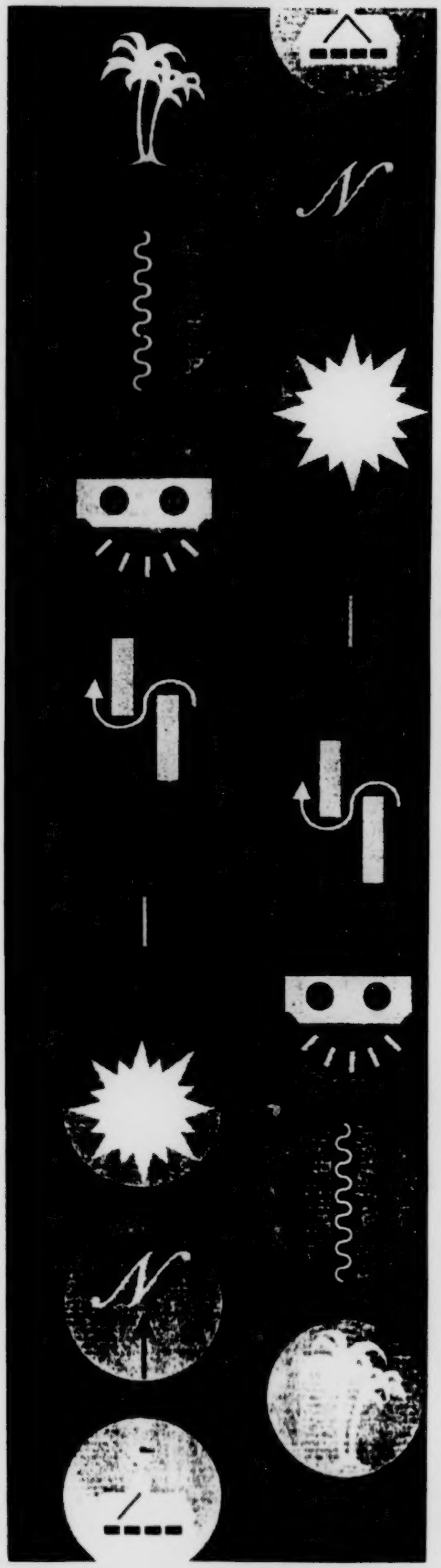
Current research suggests that ASHRAE Standard 62 recommendation of 15 cfm per person should be considered as a minimum outside air ventilation rate for classrooms (as potentially modified by average versus design occupancy). However, natural ventilation and economizer cycles were found to provide only very small savings benefits (<2% reduction in energy use) due to the high humidity levels in Florida. They are likely not cost-effective. In any case, enthalpy economizers should be used in any installation considering the use of economizer cycles. The high first and maintenance costs should be carefully weighed before specifying.

c. Dehumidification

Dehumidification of outside ventilation air will be required if a 15 cfm/person ventilation rate is adopted for the facility. Electric or base-board reheat must be avoided. Hot-gas bypass should also be avoided with packaged systems. A preferred alternative for packaged equipment is to choose high efficiency units with low sensible heat ratios (SHRs). For instance, packaged 5-ton units with an SEER of 12.0 can be located with SHRs of 0.73 or less.

Optimum system design will precondition the outside air prior to its being introduced to the indoor environment. For this, a central fresh air unit is advisable using one of the following technologies: a dedicated DX system, heat pipes, run-around coils, or a total energy recovery system. Face and bypass dampers can be used with constant volume systems. The preferred methods of first- stage air dehumidification in the central fresh air unit is with heat pipes, total energy recovery systems (TERS), or dedicated DX systems. Second-stage air conditioning and humidity removal of the outside air is performed prior to its introduction to the conditioned environment, using the conventional system either with chilled water or DX coils.

Conclusions



Performance of Individual Measures

Tables 1-3 show the predicted energy and economic performance of the individual energy conservation measures (ECMs) as simulated in Orlando, Florida. Performance is based on the energy savings of each ECM compared individually to the Base Case building prototype. Each of the three educational building prototypes are based typical Florida construction practices. The various assumptions are described in detail in Appendix A. The costs are based on cost data collected for the study from the average of three bids obtained from local vendors who would supply the equipment. The relative benefit of each ECM is the net savings identified in the far right-hand column. A nominal discount rate of 8% (real rate = 3%) is used to represent the opportunity cost of capital. Both fuel price escalation and the general economic inflation rate is assumed to be 5%. Thus, energy prices are conservatively assumed to increase at the rate of general inflation.

Brandemuehl and Beckman (1979) have formulated an economic evaluation method that is comprehensive, quick, and very useful for life cycle analysis. Two economic parameters, *P1* and *P2*, can be used to assess the life-cycle cost of any energy saving project. *P1* is the ratio in years of the present value of the life-cycle fuel savings to the first-year fuel savings. It takes into account the inflation of fuel prices over time as well as the discounting of future fuel savings according to the opportunity cost of capital:

$$P_1 = (1 - C\bar{t})PWF(N_E, i_F, d)$$

$$PWF(N,i,d) = \sum_{j=1}^{N} \frac{(1+i)^{j-1}}{(1+d)^j} \begin{cases} \frac{1}{(d-i)}\left(1-\left(\frac{1+i}{1+d}\right)^N\right) & if\ i \neq d \\ N/1+i & if\ i=d \end{cases}$$

where:

d = discount rate
i_F = fuel price inflation rate
N_E = analysis period (years)
C = flag for income producing venture
$\bar{t}$ = marginal tax bracket
PWF = present worth factor

Conclusions

The factor *P2* is the ratio of the life-cycle cost incurred over the useful life of the project against the initial capital investment. It takes into account all of the parameters that affect the investment costs over time such as financing and taxes:

$$
\begin{aligned}
P_2 &= D + (1 - D)\,\frac{PWF(N_{min},0,d)}{PWF(N_L,0,m)} - (1 - D)\bar{t} \\
&\times \left[PWF(N_{min},m,d)\left(m - \frac{1}{PWF(N_L,0,m)}\right) + \frac{PWF(N_{min},0,d)}{PWF(N_L,0,m)} \right] \\
&+ (1 - C\bar{t})\,M_s \times PWF(N_e,i,d) + t(1 - \bar{t})\,V\,x\,PWF(N_e,i,d) \\
&C\,\frac{\bar{t}}{N_D}\,PWF(N_{min},0,d) - \frac{R_v}{(1 + d)^{Ne}}
\end{aligned}
$$

where:

m = annual mortgage interest rate

i = general inflation rate

N_L = term of loan

N_{min} = years over which mortgage payments contribute to the analysis (usually the minimum of N_E or N_L)

N_D = depreciation lifetime in years

N'_{min} = years over which depreciation contributes to the analysis (usually the minimum of N_E or N_D)

t = property tax rate based on assessed value

D = ratio of down payment to initial investment

M_s = ratio of first-year miscellaneous costs (parasitic power, insurance and maintenance) to initial investment

V = ratio of assessed valuation of the ECM in first year to the initial investment in the system

R_v = ratio of resale value at the end of the period of analysis to initial investment

All economic parameters are given in their nominal terms (include inflation). The assessment allows the financial structure of an individual, firm, or institution to be assessed in the economic evaluation.

Economic Parameters Used

General inflation rate (i)	5%
Fuel price inflation rate (i_F)	5%
Discount rate (d)	8%
Finance rate (m)	8%
Property tax rate (t)	0%
Marginal tax bracket ($\bar{t}$)	0%
Down payment (D)	100%
Analysis period (N_E)	40 years
Mortgage period (N_L)	30 years
O&M fraction (M_s)	None
Resale value (R_v)	None

Electricity was assumed to cost $0.04/kWh with a monthly demand charge of $8 per kW. Natural gas was priced at $0.40/therm. These rates represent typical Florida energy costs in the second quarter of 1994. Measures were ranked by their net present value savings over the life of each individual option. The net present value savings is the difference between the life cycle savings of reduced energy use by a measure and the life cycle costs of the option (first cost amortized over its useful life along with any incremental operation and maintenance expenses).

The three tables below summarize the relative performance and economics of the individual measures analyzed for the three prototype buildings as compared with the initial base case. We caution that such an analysis cannot be used to predict the performance of a group of measures since many of the ECMs have significant interaction. For instance, addition of R-30 roof insulation would greatly reduce the savings produced by later selecting a reflective roof. Similarly, a number of the lighting options are mutually exclusive. Also, note that some measures are sensitive to the input assumptions. As example, the enthalpy recovery system (TERS) is not cost effective at the current minimum ventilation rate of 5 cfm per student, but is quite economic when the ventilation rate is increased to 15 cfm as recommended by ASHRAE Standard 62-1989.

Table 1
Economic and Energy Analysis of Single Energy Conservation Measures--Classroom Building

	Run #	Units	Cost/unit	**First Cost**	Multiplier	Multiplier	Oper and Maint	Life of ECM	**Life Cycle Cost**	Annual Energy Cost	Annual Energy Savings	Multiplier	**Life Cycle Savings**	**Net Savings**	Energy Use Intensity	Estimated Cooling Capacity
Formula		sqft except where noted		FC	P2	P3	O&M		**LCC= (FCxP2)+ (FCxP3xOM)**	Electric cost +Gas cost	Base Case energy cost - ECM energy cost	P1	**LCS=(Annual Energy Savings)(P1)**	**LCS-LCC**		
Energy Conservation Measure			$	**$**	--	--	--	year	**$**	$	$	--	**$**	**$**	kBTU/sqft	Tons
Class Room Building Base Case	--	--	--	--	--	--	--	40	--	**$15,481**	--	--	**$0**	-	44	46
Single pane reflective glazing	11	2304	$3	**$6,600**	1.031	0.307	0	40	**$6,806**	$15,092	$389	57.8	**$22,499**	**$15,696**	43	45
Double pane clear glazing	8	2304	$2	**$5,300**	1.031	0.307	0	40	**$5,464**	$15,495	$-14	57.8	**$-822**	**$-6,287**	44	45
Double pane reflective glazing	13	2304	$6	**$14,867**	1.031	0.307	0	40	**$15,328**	$14,462	$1,019	57.8	**$58,910**	**$43,582**	41	42
Double pane spectrally selective glazing	15	2304	$4	**$9,600**	1.031	0.307	0	40	**$9,898**	$14,409	$1,072	57.8	**$61,961**	**$52,063**	40	41
3.5' Window shade	57	385	$5	**$1,925**	1.031	0.307	0	40	**$1,985**	$15,380	$101	57.8	**$5,810**	**$3,825**	43	44
2' Window shade	58	220	$5	**$1,100**	1.031	0.307	0	40	**$1,134**	$15,450	$31	57.8	**$1,793**	**$659**	43	46
2' Light shelf	59	220	$5	**$1,100**	1.031	0.307	0	40	**$1,134**	$15,422	$59	57.8	**$3,402**	**$2,267**	43	45
Covered Walkway	56	880	$5	**$4,400**	1.031	0.307	0	40	**$4,536**	$14,951	$530	57.8	**$30,611**	**$26,074**	42	44
Reflective roof	20	14835	$0	**$0**	1.031	0.554	0	20	**$0**	$14,941	$540	23.4	**$12,641**	**$12,641**	42	46
Reflective wall	21	6816	$0	**$0**	1.031	0.554	0	20	**$0**	$15,389	$92	23.4	**$2,151**	**$2,151**	43	46
2' overhang NSEW	22	1152	$5	**$5,760**	1.031	0.307	0	40	**$5,939**	$15,442	$39	57.8	**$2,232**	**$-3,706**	43	46
4' overhang NSEW	23	2336	$5	**$11,680**	1.031	0.307	0	40	**$12,042**	$15,351	$130	57.8	**$7,538**	**$-4,504**	43	45
Shade trees	24	8 trees	$200	**$1,600**	1.031	0.412	0	30	**$1,650**	$15,313	$168	39	**$6,558**	**$4,909**	43	46
R-11 wall insulation	25	6816	0.31	**$2,113**	1.031	0.307	0	40	**$2,178**	$15,547	$-66	57.8	**$-3,808**	**$-5,987**	44	46
R-19 roof insulation	26	14835	0.31	**$4,599**	1.031	0.307	0	40	**$4,741**	$15,576	$-96	57.8	**$-5,520**	**$-10,261**	44	49
R-30 roof insulation	28	14835	0.31	**$4,599**	1.031	0.307	0	40	**$4,741**	$15,240	$241	57.8	**$13,925**	**$9,183**	43	45

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Variable speed circulation pump for chiller	39	1 pump	$3,000	**$3,000**	1.031	0.642	0	15	**$3,093**	$15,237	$244	16.7	**$4,076**	**$983**	43	47
Non-Optimal Orientation	1	1	$0	**$0**	1.031	0.307	0	40	**$0**	$15,726	$-245	57.8	**$-14,156**	**$-14,156**	45	45
F40, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	30	400 fixts	$15	**$6,000**	1.031	0.642	0	15	**$6,186**	$16,058	$-577	16.7	**$-9,629**	**$-15,815**	45	47
F34, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	31	400 fixts	$15	**$6,000**	1.031	0.642	0	15	**$6,186**	$15,383	$98	16.7	**$1,636**	**$-4,550**	43	46
F34, T12, electronic ballast, open diffuser, parabolic troffer	32	400 fixts	$8	**$3,200**	1.031	0.642	0	15	**$3,299**	$14,330	$1,151	16.7	**$19,218**	**$15,919**	40	45
F32, T8, electronic ballast, open diffuser, parabolic troffer	33	400 fixts	$24	**$9,700**	1.031	0.642	0	15	**$10,001**	$13,854	$1,627	16.7	**$27,167**	**$17,166**	39	44
LED exit signs	34	12 signs	$40	**$480**	1.031	0.307	0	40	**$495**	$15,291	$190	57.8	**$10,991**	**$10,496**	43	46
Occupancy sensors	61	12 snsrs	$60	**$720**	1.031	0.642	0	15	**$742**	$14,492	$989	16.7	**$16,515**	**$15,773**	41	45
Screw chiller	36	1 chlr	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$12,686	$2,795	16.7	**$46,674**	**$44,200**	35	47
Enthalpy Economizer (163)	49	1 ecnzr	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$15,462	$19	16.7	**$316**	**$-2,158**	43	46
Optimal Start (Energy Management System)	48	1 EMS	$5,000	**$5,000**	1.031	0.642	0	15	**$5,155**	$15,019	$462	16.7	**$7,715**	**$2,560**	41	46
Enthalpy Recovery System (TERS) for 5 cfm	46	per ton (47)	$400	**$-18,800**	1.031	0.554	0.05	15	**$-19,904**	$16,848	$-1,367	16.7	**$-22,823**	**$-2,919**	42	45
Enthalpy Recovery System (TERS) for 15 cfm [Compared to ventilation rate = 15cfm/person]	47	per ton (47)	$400	**$-18,800**	1.031	554	05	15	**$-19,904**	$17,165	$94	16.7	**$1,566**	**$21,470**	47	59

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Table 2
Economic and Energy Analysis of Single Energy Conservation Measures -- Administration Building

	Run #	Units	Cost/ unit	**First Cost**	Multiplier	Multiplier	Oper and Main	Life of ECM	**Life Cycle Cost**	Annual Energy Cost	Annual Energy Savings	Multiplier	**Life Cycle Savings**	**Net Savings**	Energy Use Intensity	Estimated Cooling Capacity
Formula		sqft except where noted		**FC**	P2	P3	O&M	Life of ECM	**LCC= (FC)(P2)+ (FC)(P3)(OM)**	Electric cost + Gas cost	Base Case energy cost -ECM cost	P1	**LCS= (Annual Energy Savings)(P1)**	**LCS - LCC**		
Energy Conservation Measure			$	$	--	--	--	years	$	$	$	--	$	$	kBTU/sqft	Tons
Administration Building Base Case	--	--	--	--	--	--	--	--	**$0**	**$9,735**	--	--	--	--	**42**	**25**
Single pane reflective glazing	11	629.6	$3	**$1,304**	1.031	.307	0	40	**$1,359**	$9,067	$668	57.8	**$38,587**	**$36,727**	40	23
Double pane clear glazing	8	629.6	$2	**$1,448**	1.031	.307	0	40	**$1,493**	$9,743	$-8	57.8	**$-477**	**$-1,971**	42	24
Double pane reflective glazing	13	629.6	$6	**$4,063**	1.031	.307	0	40	**$4,189**	$9,098	$637	57.8	**$36,821**	**$32,632**	40	22
Double pane spectrally selective glazing	15	629.6	$4	**$2,623**	1.031	.307	0	40	**$2,705**	$9,014	$721	57.8	**$41,651**	**$38,946**	40	22
Reflective roof	20	10017	$0	**$0**	1.031	.554	0	20	**$0**	$9,300	$435	23.4	**$10,185**	**$10,185**	41	25
Reflective wall	21	5328	$0	**$0**	1.031	.554	0	20	**$0**	$9,664	$71	23.4	**$1,654**	**$1,654**	42	25
2' overhang NSEW	22	904	$5	**$4,520**	1.031	.307	0	40	**$4,660**	$9,710	$24	57.8	**$1,411**	**$-3,249**	29	25
4' overhang NSEW	23	5632	$5	**$28,160**	1.031	.307	0	40	**$29,033**	$9,653	$82	57.8	**$4,751**	**$-24,282**	28	24
Shade trees	24	8 trees	$200	**$1,600**	1.031	.412	0	30	**$1,650**	$9,564	$171	39	**$6,673**	**$5,024**	42	25
R-11 wall insulation	25	5328	$0.31	**$1,652**	1.031	.307	0	40	**$1,703**	$9,790	$-55	57.8	**$-3,182**	**$-4,885**	42	25
R-19 roof insulation	26	10017	$0.31	**$3,105**	1.031	.307	0	40	**$3,202**	–	$9,735	57.8	**$562,671**	**$559,469**	43	26
R-30 roof insulation	28	10017	$0.31	**$3,105**	1.031	.307	0	40	**$3,202**	$9,508	$227	57.8	**$13,118**	**$9,916**	42	24
Variable Speed Circ. Pump	39	1	$3,000	**$3,000**	1.031	.642	0	15	**$3,093**	$9,634	$101	16.7	**$1,688**	**$-1,405**	42	25
Non-Optimal Orientation	1	1	$0	**$0**	1.031	.307	0	40	**$0**	$9,937	$-202	57.8	**$-11,704**	**$-11,704**	44	24
F40, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	30	270 fixts	$15	**$4,050**	1.031	.642	0	15	**$4,176**	$10,132	$-398	16.7	**$-6,640**	**$-10,816**	44	25

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F34, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	31	270 fixts	$15	**$4,050**	1.031	.642	0	15	**$4,176**	$9,668	$67	16.7	**$1,118**	**$-3,057**	42	25
F34, T12, electronic ballast, open diffuser, parabolic troffer with reflector	32	270 fixts	$8	**$2,160**	1.031	.642	0	15	**$2,227**	$8,950	$785	16.7	**$13,113**	**$10,886**	39	24
F32 T8 electronic ballast, open diffuser, parabolic troffer	33	270 fixts	$24	**$6,548**	1.031	.642	0	15	**$6,750**	$8,624	$1,110	16.7	**$18,544**	**$11,794**	38	23
LED exit signs	34	12 signs	$40	**$480**	1.031	.307	0	40	**$495**	$9,668	$67	57.8	**$3,871**	**$3,376**	42	25
Occupancy sensors	61	12 snsrs	$60	**$720**	1.031	.642	0	15	**$742**	$9,338	$397	16.7	**$6,632**	**$5,890**	41	25
Screw chiller	36	1 chiller	$2,400	**$2,400**	1.031	.642	0	15	**$2,474**	$8,656	$1,079	16.7	**$18,016**	**$15,541**	37	25
Enthalpy economizer	49	1 ecnmz	$2,400	**$2,400**	1.031	.642	0	15	**$2,474**	$9,715	$20	16.7	**$327**	**$-2,147**	42	25
Optimal start (Energy Management System)	48	1 EMS	$5,000	**$5,000**	1.031	.642	0	15	**$5,155**	$9,627	$108	16.7	**$1,803**	**$-3,352**	42	25
Enthalpy recovery system (TERS) for 5 cfm	46	per ton (25)	$400	**$-10,000**	1.031	.554	0.05	15	**$-10,587**	$9,583	$152	16.7	**$2,538**	**$13,125**	42	24
Enthalpy recovery system (TERS) for 15 cfm (Compared to ventilation rate = 15cfm/per)	47	per ton (25)	$400	**$-10,000**	1.031	.554	0.05	15	**$-10,587**	$10,124	$288	16.7	**$4,815**	**$15,402**	43	28

142

143

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Table 3
Economic and Energy Analysis of Single Energy Conservation Measures -- Multi Purpose Building

	Run #	Units	Cost/ unit	**First Cost**	Multiplier	Multiplier	Oper and Main	Life of ECM	**Life Cycle Cost**	Annual Energy Cost	Annual Energy Savings	Estimated Cooling Capacity	**Life Cycle Savings**	**Net Savings**	Energy Use Intensity	Estimated Cooling Capacity
Formula		sqft except where noted		FC	0	Tons	O&M		**LCC= (FC)(P2)+ (FC)(P3)(OM)**	Electric cost +Gas cost	Base Case energy Cost - ECM energy cost	P1	**LCS= (Annual Energy Savings)(P1)**	**LCS-LCC**		
Energy Conservation Measure			$	**$**	--	--	--	years	**$**	$	$	- -	**$**	**$**	kBTU/sq ft	Tons
Multi Purpose Building Base Case	--	--	--	--	--	--	--	--	--	**$4,609**	--	--	--	--	16.15	**20**
Single pane reflective glazing	11	534	$3	**$1,602**	1.031	0.307	0	??	**$1,652**	$3,942	$667	57.8	**$38,553**	**$36,901**	15.94	17
Double pane clear glazing	8	534	$2	**$1,068**	1.031	0.307	0	40	**$1,101**	$4,520	$89	57.8	**$5,144**	**$4,043**	15.12	20
Double pane reflective glazing	13	534	$6	**$3,204**	1.031	0.307	0	40	**$3,303**	$3,786	$823	57.8	**$47,569**	**$44,266**	14.56	16
Double pane spectrally selective	15	534	$4	**$2,225**	1.031	0.307	0	40	**$2,294**	$3,694	$915	57.8	**$52,887**	**$50,593**	14.11	16
Reflective roof	20	13353	$0	**$0**	1.031	0.554	0	20	**$0**	$4,484	$125	23.4	**$2,925**	**$2,925**	16.02	19
Reflective wall	21	9250	$0	**$0**	1.031	0.554	0	20	**$0**	$4,559	$50	23.4	**$1,170**	**$1,170**	16.21	20
2' overhang NSEW	22	1723	$5	**$8,615**	1.031	0.307	0	40	**$8,882**	$4,604	$5	57.8	**$289**	**$-8,593**	16.14	20
4' overhang NSEW	23	2064	$5	**$10,320**	1.031	0.307	0	40	**$10,640**	$4,580	$29	57.8	**$1,676**	**$-8,964**	16.08	20
Shade trees	24	8 trees	$200	**$1,600**	1.031	0.412	0	30	**$1,650**	$4,322	$287	39	**$11,193**	**$9,543**	16.00	18
R-11 wall insulation	25	9250	$0.31	**$2,868**	1.031	0.307	0	40	**$2,956**	$5,670	$-1,061	57.8	**$-61,326**	**$-64,282**	15.46	20
R-19 roof insulation	26	9250	$0.31	**$2,868**	1.031	0.307	0	40	**$2,956**	$5,400	$-791	57.8	**$-45,720**	**$-48,676**	16.31	20
R-30 roof insulation	28	13353	$0.31	**$4,139**	1.031	0.307	0	40	**$4,266**	$5,78.	$-1,175	57.8	**$-67,915**	**$-72,183**	15.87	20
Variable speed circ. pump for chiller	39	1 pump	$3,000	**$3,000**	1.031	0.642	0	15	**$3,093**	$5,500	$-891	16.7	**$-14,880**	**$-17,973**	15.57	20
F34, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	31	359 fxts	$15	**$5,385**	1.031	0.642	0	15	**$5,552**	$4,596	$13	16.7	**$217**	**$-5,335**	16.12	22

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F34, T12, magnetic ballast, open diffuser, parabolic troffer with reflector	32	359 fxts	$8	**$2,872**	1.031	0.642	0	15	**$2,961**	$4,460	$149	16.7	**$2,488**	**$-478**	15.75	20
F32, T8 electronic ballast, open diffuser, parabolic troffer	33	359 fxts	$24	**$8,706**	1.031	0.642	0	15	**$8,976**	$4,399	$210	16.7	**$3,507**	**$-5,469**	15.58	20
Screw chiller	36	1 chlr	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$3,566	$1,043	16.7	**$17,418**	**$14,944**	12.47	20
Optimal start (Energy Management System)	48	1 EMS	$5,000	**$5,000**	1.031	0.642	0	15	**$5,155**	$5,466	$-857	16.7	**$-14,312**	**$-19,467**	14.91	20
LED exit signs	34	8 signs	$40	**$320**	1.031	0.307	0	40	**$330**	$5,644	$-1,035	10.6	**$-10,971**	**$-11,301**	17.94	21
Enthalpy economizer	49	1	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$5,672	$-1,063	16.7	**$-17,752**	**$-20,227**	16.12	20
Non-Optimal orientation	1	1	$0	**$0**	1.031	0.307	0	40	**$0**	$4,835	$-226	57.8	**$-13,063**	**$-13,063**	17.94	21
Enthalpy recovery system (TERS) for 5 cfm	46	per ton (20)	$400	**$8,000**	1.031	0.554	0.05	20	**$8,470**	$5,018	$-409	16.7	**$-6,830**	**$-15,300**	14.86	17
Enthalpy recovery system (TERS) for 15 cfm [Compared to ventilation rate = 15cfm/person]	47	per ton (20)	$400	**$8,000**	1.031	0.554	0.05	20	**$8,470**	$4,607	$2	16.7	**$33**	**$-8,436**	16.13	20

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Conclusions

Technical Potential to Reduce Energy Use

Most energy efficiency improvements for educational facilities behave according to a law of diminishing returns. The fundamental characteristic is one of decreasing savings associated with the addition of each increment designed to reduce the building or machine thermal load. As a result, we analyzed the *incremental* energy savings associated with each energy conservation measure (ECM) for each building prototype. With this approach, optimization by steepest descent is used to determine the order in which measures were added. This means that the measure with the greatest savings is chosen first, and implemented in the Base Case building, before re-evaluating the remaining measures for the next choice. In this way, it is possible to determine a "technical optimum" series of ECMs ranked in terms of their performance at reducing energy use.

This assessment, obviously does not consider cost. Although a cost-effectiveness analysis is ultimately desirable, we wished to determine the most superior group of performance measures independent of cost since the expense of some newer high-technology options may change over time. Measures that appear promising, but are yet too expensive, may be targeted for efforts to reduce their cost.

Tables 4-6 show the technical optimization results for each building prototype. The selected ECMs comprise the package of options determined to provide the maximum reduction in facility energy use under the assumptions used in our study. Different measure performance between the various prototypes depend, in large part, on the different occupancy densities and use schedules between the different buildings.

The analysis results show that energy use in the three prototypes can be potentially reduced by 46-62% using available technologies. Cooling system size can be lowered by 21-24%.

Table 4
Technical Optimization of ECMs--Classroom Building

Class Room Building Technical Optimization	Run	Annual Energy Use Intensity	Annual Electric Consumption	Annual Gas Consumption	Annual Energy Cost	Cooling Capacity
	#	kBTU/sqft	kWh	Therms	$	Tons
Base Case		44	186239	103	17400	46
Screw Chiller	36	35	151681	86	12686	47
F32 T-8 Electronic Ballast	33	31	133962	97	11220	44
Dimming Electronic Ballast	7	29	123145	101	10433	42
Occupancy Sensors	61	28	116510	106	9798	41
Double Pane Spectrally Selective Glazing	15	26	111848	103	9264	37
Enthalpy Recovery (ERS) at ventilation rate = 5 cfm	46	25	108099	91	8934	36
Reflective Roof	20	25	104397	96	8459	35
Optimal Start (Energy Management System)	48	24	102230	74	8444	35
Variable Speed Pumps (for chiller)	39	24	100739	72	8339	35

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Table 5
Technical Optimization of ECMs--Administration Building

Administrative Building Technical Optimization	Run	**Annual Energy Use Intensity**	Annual Electrical Consumption	Annual Gas Consumption	Annual Energy Cost	Cooling Capacity
	#	**kBTU/sqft**	kWh	Therms	$	Tons
Base Case		**42**	122670	60	9735	25
Screw Chiller	16	**36**	104658	51	8270	25
F32 T-8 Electronic Ballast	12	**32**	85167	63	7261	23
Dimming Electronic Ballast	7	**30**	85167	65	6771	22
Double Pane Spectrally Selective Glazing	15	**19**	82367	58	6404	19
Optimal Start (Energy Management System)	48	**16**	81034	40	6340	19

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Conclusions

Economic Optimization Analysis

Measures showing a positive life cycle net saving in the single-measure economic test were subjected to an incremental analysis to choose those which were cost effective under a more stringent criteria. As before, the system life cycle net savings was used to decide on the winning options. An incremental analysis is more rigorous since most conservation related improvements are subject to steadily diminishing returns. This analysis examines all measures competing against each other to determine their economic ranking relative. After all options are assessed, the winning incremental option is incorporated into the Base building after which all remaining options are then reassessed. The process of selecting measures and incorporating them into the building continues until all measures are included, or there are no longer any cost effective options remaining. Interactions are taken into account by the computer simulation of the measures as they are incorporated into the building in a step-wise fashion.

Tables 7-9 and Figures 43-45 show how overall building energy use and associated expenses over the life of the project is reduced as measures are added in an incremental fashion. Note that the lifecycle savings greatly outweigh the cumulative initial costs of the ECMs. Results are presented for each of the three prototypes. The package of selected measures with this procedure represents the optimum mix of ECMs based on our assumed costs, building and equipment parameters and operation related assumptions.

Obviously, the relative economics of the various options could vary greatly under differing cost or use assumptions. Thus, these results should be used to guide ECM selection, rather than to be seen as the final word in energy-efficiency for school design. It does, however, suggest how a package of ECMs can be chosen for the design of an educational facility to address the building's major energy end-uses. Also, the order in which the measures were selected in the optimization process provides useful information to design teams about the relative ranking of ECMs for capital constrained projects. Some measures, such as a more efficient chiller and low-shading coefficient windows, are shown to be uniformly cost effective and highly desirable in each analysis.

The results differ for the three building prototypes, primarily due to differences in occupant density and use schedules for the buildings. Perhaps the largest caveat regards the assumed ventilation rate for the buildings, which is 5 cfm/student under current Florida Department of Education 6A-2 regulations. It appears likely that the state may adopt ASHRAE Standard 62-1989 in the near future. This will require an outside ventilation rate of 15 cfm per student. Our analysis showed that if this ventilation standard is adopted, that use of enthalpy recovery systems, or other alternative means of controlling humidity and mitigating the standard's effects will immediately become very cost effective for Florida educational facilities.

Regardless, the analysis showed that it is possible to reduce energy use in the three prototype facilities by 41-44% in a cost-effective fashion. The same package of optimum energy-efficiency measures reduces the required cooling system size by 22-24% resulting in additional project cost savings that we did not include in our conservative assessment.

Table 7
Economic Optimization Analysis--Classroom Building

	Run #	Units	Cost/ unit	**First Cost**	Multi- plier	Multi- plier	Oper and Maint	Life of ECM	**Life Cycle Cost**	Annual Energy Cost	Annual Energy Savings	Multi- plier	**Life Cycle Savings**	**Net Savings**	**Energy Use Intensity**	**Estimated Cooling Capacity**
Formula		sqft except where noted		FC	P2	P3	O&M		LCC=(FC)(P2)+(FC)(P3)(OM)	Electric cost +Gas cost	Base Case energy cost - ECM energy cost	P1	LCS=(Annual Energy Savings)(P1)	LCS-LCC		
Energy Conservation Measure			$	$	--	--	--	year	$	$	$	--	$	$	kBTU/sq ft	Tons
Class Room Building Base Case	--	--	--	--	--	--	--	**40**	--	**$15,481**	--	--	$0	-	**44**	**46**
Double pane spectrally selective glazing	15	2304	$4	**$9,600**	1.031	0.307	0	40	**$9,898**	$14,409	$1,072	57.8	**$61,961**	**$52,063**	41	42
Screw chiller	36	1	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$12,014	$2,395	16.7	**$39,994**	**$37,520**	34	42
F32, T8, electronic ballast, open diffuser, parabolic troffer	33	400	$24	**$9,700**	1.031	0.642	0	15	**$10,001**	$10,471	$1,543	16.7	**$25,765**	**$15,765**	30	39
Occupancy sensors	61	12	$60	**$720**	1.031	0.642	0	15	**$742**	$9,774	$697	16.7	**$11,645**	**$10,903**	28	38
Reflective roof	20	14835	$0	**$0**	1.031	0.554	0	20	**$0**	$9,396	$378	23.4	**$8,837**	**$8,837**	27	38
Electronic dimming ballast	7	400 bllsts	$14	**$5,400**	1.031	.642	0	15	**$5,567**	$8,810	$586	16.7	$9,781	**$4,213**	26	36
LED exit signs	34	12	$40	**$480**	1.031	0.307	0	40	**$495**	$8,743	$67	57.8	**$3,888**	**$3,393**	25	36
Reflective wall	21	6816	$0	**$0**	1.031	0.554	0	20	**$0**	$8,736	$7	23.4	$162	**$162**	25	36

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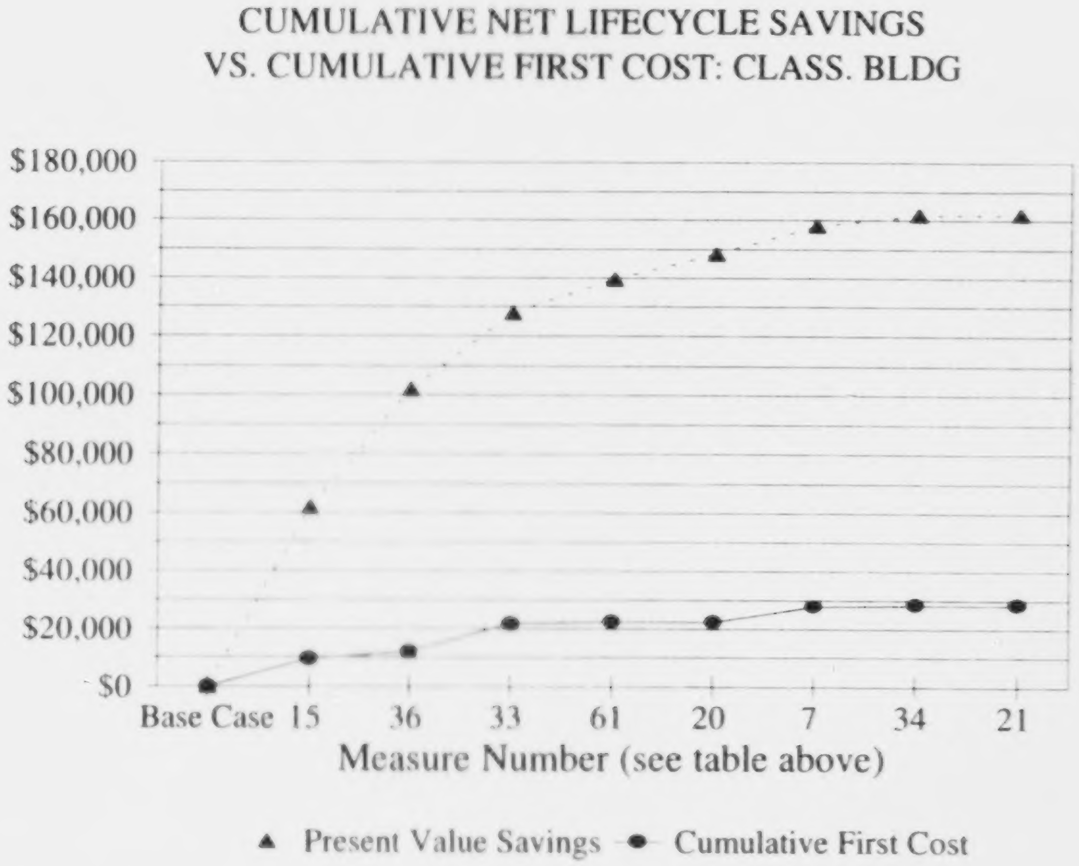
CUMULATIVE NET LIFECYCLE SAVINGS
VS. CUMULATIVE FIRST COST: CLASS. BLDG
$180,000
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Base Case
15
36
33
61
20
7
34
21
Measure Number (see table above)
▲ Present Value Savings
● Cumulative First Cost

Figure 43

Table 8
Economic Optimization Analysis -- Administration Building

	Run #	Units	Cost/ unit	First Cost	Multiplier	Multiplier	Oper and Main	Life of ECM	Life Cycle Cost	Annual Energy Cost	Annual Energy Savings	Multiplier	Life Cycle Savings	Net Savings	Energy Use Intensity	Estimated Cooling Capacity
Formula		sqft except where noted		FC	P2	P3	O&M	Life of ECM	LCC= (FCxP2)+ (FCxP3xOM)	Electric cost + Gas cost	Base Case energy cost -ECM cost	P1	LCS= (Annual Energy Savings)(P1)	LCS - LCC		
Energy Conservation Measure			$	$	--	--	--	years	$	$	$	--	$	$	kBTU/sq ft	Tons
Administrative Building Base Case	--	--	--	--	--	--	--	--	$0	$9,735	--	--	--	--	42	26
Double pane spectrally selective	15	629 6	$4	$2,623	1 031	307	0	40	$2,706	$9,014	$721	57 8	$41,651	$38,946	40	22
Screw chiller	36	1 chiller	$2,4 00	$2,400	1 031	642	0	15	$2,474	$7,776	$1,238	16 7	$20,677	$18,203	34	22
F32, T8,electronic ballast, open diffuser, parabolic troffer	33	270 fxts	$24	$6,548	1 031	642	0	15	$6,750	$6,774	$1,002	16 7	$16,726	$9,976	30	20
Occupancy sensors	61	12 snsrs	$60	$720	1 031	642	0	15	$742	$6,314	$460	16 7	$7,676	$6,934	29	20
Reflective roof	20	10017	$0	$0	1 031	554	0	20	$0	$6,030	$284	23 4	$6,646	$6,646	28	19
Electronic dimming ballast	7	270 bllsts	$14	$3,645	1 031	642	0		$3,758	$5,700	$330	16 7	$5,508	$1,750	26	18
LED exit signs	34	12 signs	$40	$480	1 031	307	0	40	$496	$5,626	$74	57 8	$4,294	$3,799	26	18
Reflective wall	21	5328	$0	$0	1 031	554	0	20	$0	$5,622	$4	23 4	$88	$88	26	18

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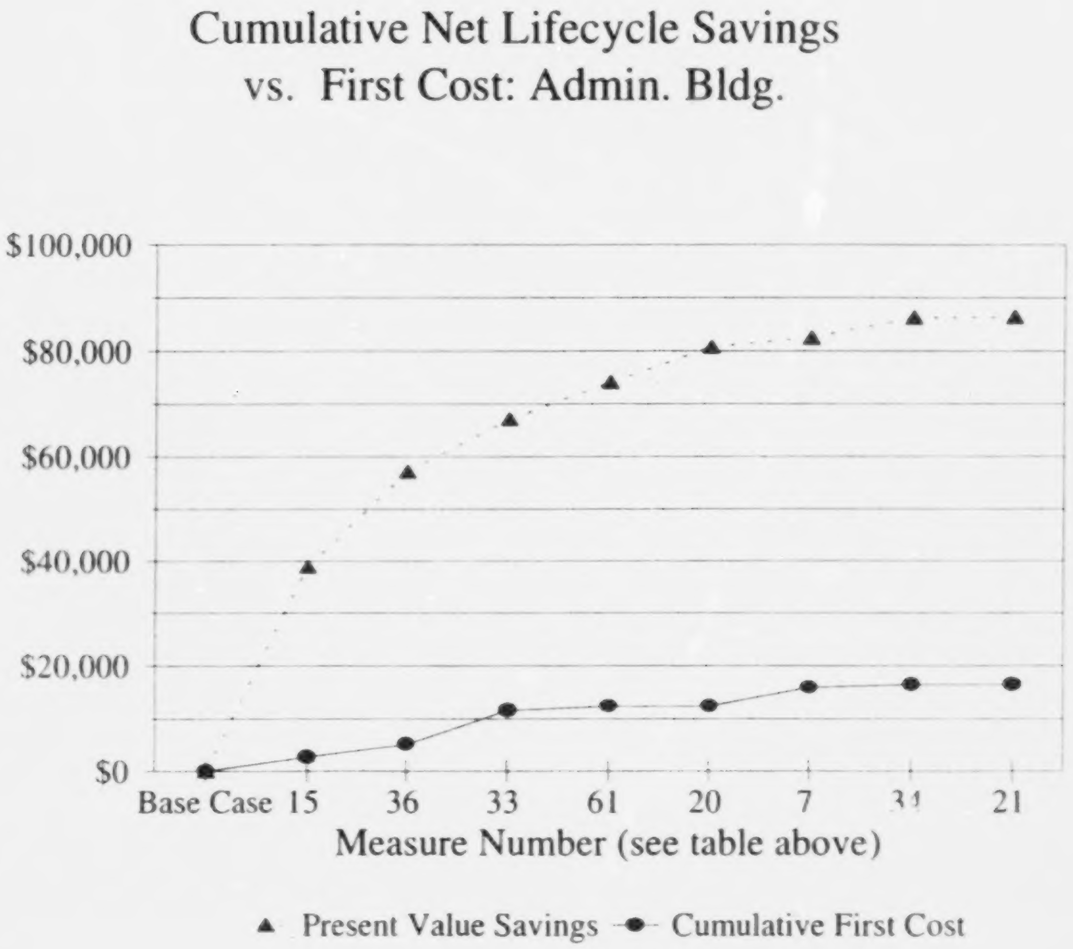
Cumulative Net Lifecycle Savings
vs. First Cost: Admin. Bldg.
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Base Case
15
36
33
61
20
7
31
21
Measure Number (see table above)
▲ Present Value Savings
-●- Cumulative First Cost

Figure 44

Table 9
Economic Optimization Analysis -- Multi Purpose Building

	Run #	Units	Cost/ unit	**First Cost**	Multi- plier	Multi- plier	Oper and Main	Life of ECM	**Life Cycle Cost**	Annual Energy Cost	Annual Energy Savings	Multi- plier	**Life Cycle Savings**	**Net Savings**	Energy Use Intensity	Estimated Cooling Capacity
Formula		sqft except where noted		FC	0	Tons	O&M		**LCC= (FC)(P2)+ (FC)(P3)(OM)**	Electric cost +Gas cost	Base Case energy Cost - ECM energy cost	P1	**LCS= (Annual Energy Savings)(P1)**	**LCS- LCC**		
Energy Conservation Measure			$	**$**	–	–	–	years	**$**	$	$	- -	$	**$**	kBTU/sq ft	Tons
Multi Purpose Building Base Case	–	–	–	–	–	--	–	–	–	**$4,069**	–	–	–	–	**16.15**	**20**
Double pane spectrally selective	15	534	$4	**$2,225**	1.031	0.307	0	40	**$2,294**	$3,154	$915	57.8	**$52,887**	**$50,593**	14.11	16
Screw chiller	36	1 chlr	$2,400	**$2,400**	1.031	0.642	0	15	**$2,474**	$2,355	$799	16.7	**$13,345**	**$10,871**	11.28	16
Reflective roof	20	13353	$0	**$0**	1.031	0.554	0	20	**$0**	$2,305	$50	23.4	**$1,179**	**$1,179**	11.42	15
R-19 roof insulation	26	9250	$0.31	**$2,868**	1.031	0.307	0	40	**$2,956**	$2,247	$58	57.8	**$3,378**	**$421**	11.86	15

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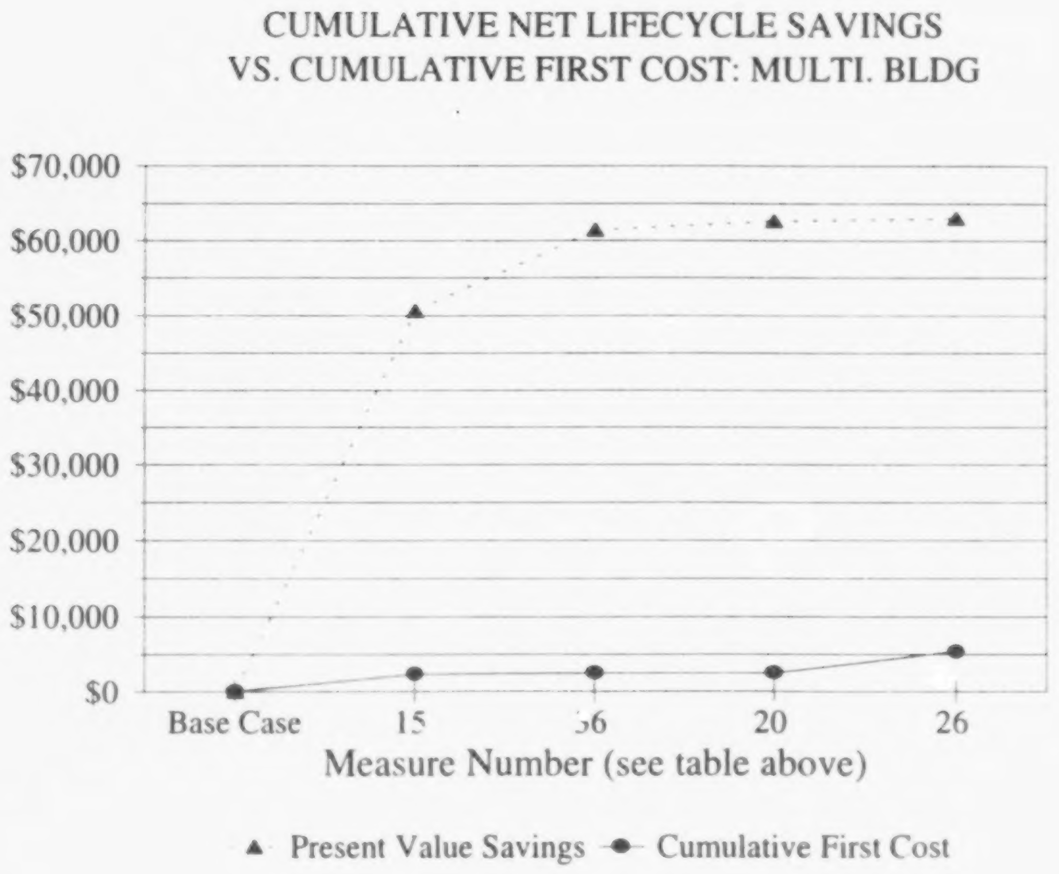
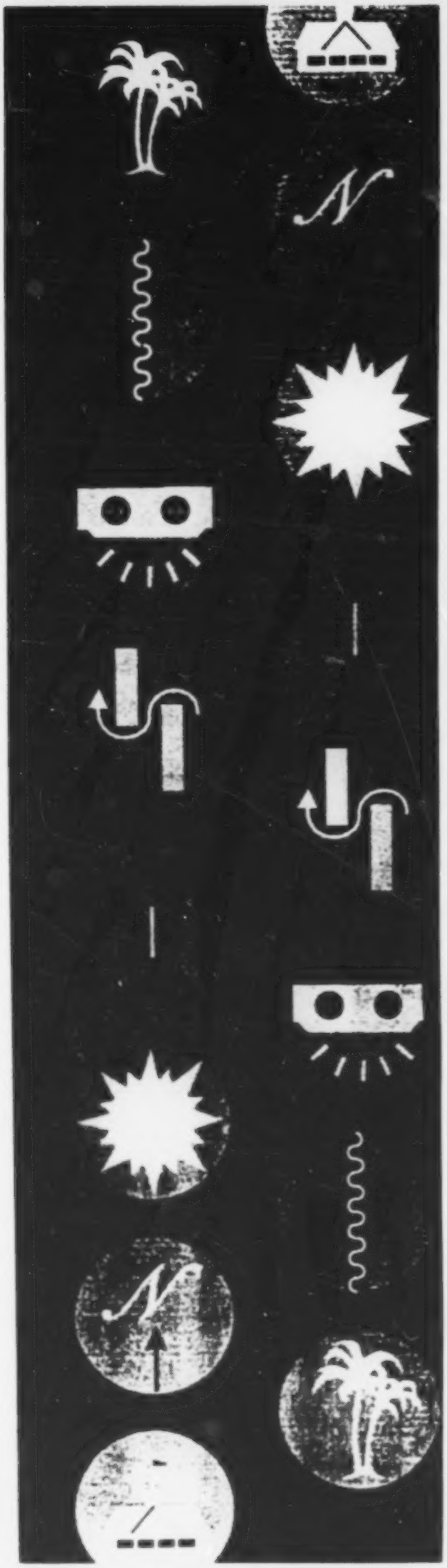

CUMULATIVE NET LIFECYCLE SAVINGS
VS. CUMULATIVE FIRST COST: MULTI. BLDG
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Base Case
15
36
20
26
Measure Number (see table above)
▲ Present Value Savings
● Cumulative First Cost

Figure 45

Case Studies



APPLYING WHAT WE KNOW

As this manual is new, specific application of its recommendations in new Florida educational facilities must await future projects. Currently, we are aware of one project, Celebration Middle School in Orlando, being designed by *Schenkel Schultz Architecture/Interior Design* who plan to incorporate some strategies explored in this manual.

We are also aware of several school districts persuing retrofit energy conservation with great success. Two HVAC retrofits are described here to illustrate how some of the specific technologies can be incorporated into existing educational facilities. Another case study explains Pasco County's Comprehensive Energy Management Program. If readers are aware of other such projects, we would appreciate receiving information on these so that we might help document and dissiminate the results of these.

RENOVATION OF EXISTING SCHOOL HVAC SYSTEMS IN HUMID CLIMATES

Brian Cumming
R.Douglas Stone Associates, Inc.

Florida's hot, humid climate is typical for tropical and subtropical locations throughout the world. ASHRAE Standards 62-89 and 55-92 potentially have a tremendous impact on the initial cost, energy consumption costs, in such a climate. These two standards will especially affect schools which usually have a high occupant density and large swings in heat loads based upon time of day.

Since the late 1970's, most HVAC systems in Florida schools have been designed for a constant ventilation of 5 cfm/occupant. There have been many humidity problems even at this ventilation rate. Test and balance data in many schools has shown daily humidities of 60 to 80+ percent during fall and spring periods. These humidity levels have been recorded for all types of systems. However, high humidities are most prevalent in schools with HVAC systems that have constant volume supply air where unconditioned ventilation air is introduced into the return air duct or plenum, the supply fan runs continuously and the cooling compressor (or chilled water valve) cycles to meet space temperature. These systems include all single coil DX system types with no reheat, popular unit ventilators, PTAC, and fan coil systems. Psychometric analysis shows that these systems cannot maintain space humidities under 60% during part load conditions without the use of reheat.

Many indoor air quality (IAQ) complaints in schools arise because of high humidity, poor temperature control, and lack of fresh air. These are usually because the HVAC systems cannot maintain acceptable humidity levels at part load conditions even at 5 cfm/student. Many time ventilation dampers are closed by maintenance staff to reduce humidities at the hazard of increasing carbon dioxide levels, decreasing air quality, and increasing occupant illness.

ASHRAE Standard 62-89 recommends ventilation rates should be a minimum of 15 cfm/student in classroom spaces. Typical classrooms require about 900 to 1200 cfm of supply air at 55°F at peak conditions. Typically, there are about 30 students in a classroom which require about 450 cfm of ventilation air, or about 40% of the total air required. This poses unique challenges for the project engineer in order to successfully retrofit the existing school HVAC systems. There are two paths that can be used to retrofit school HVAC equipment:

1. *Reusing Existing Equipment*

   If the airside equipment is relatively new and in good condition, it may be most economical to reuse existing HVAC equipment. Usually, the equipment cannot accommodate the increased ventilation cooling and heating loads. Therefore, the best means of augmenting ventilation is to add dedicated outside air systems which supply dehumidified, preconditioned outside air directly into the spaces or into the return of the existing equipment. These can be packaged DX outside air equipment or chilled water air handling units. Both types will require some means of reheat.

   Since school occupancy densities are high, consideration should be given to provide the outside air directly to the space and distribute it uniformly while allowing the recirculating unit fan to cycle off with cooling to satisfy space temperature. This mode of operation eliminates re-evaporation of water on the coil to the supply air stream when the compressor is off. This is particularly important for unit ventilators, fan coil units, and constant volume systems. VAV systems will require the same approach to comply with *6-A2* requirements and ***ASHRAE Standard** 62-89* requirements.

Exhaust systems will be required to provide the additional ventilation air. It is advised to provide one central exhaust system that is interlocked with the dedicated ventilation air handling system. Return air or exhaust plenums are strongly discouraged.

To minimize energy usage, new control points and sequences will be required to monitor and actively control humidity. CO_2 levels may also require monitoring for verification of system function.

2. *Replacing Complete HVAC System*

This option should be exercised if the existing equipment is beyond it's useful life, damaged, or inadequate to meet the needs of the current occupancy. If it has been determined that existing ductwork requires replacement, the cost of adding new systems is usually justified.

Note that many previously used HVAC system types used with 5 cfm/occupant will not maintain humidities less than 60% during part load conditions. It is important to exercise caution in considering acceptable types of systems. System types considered should include constant volume DX with reheat (use of condenser heat to provide reheat), VAV with dedicated outside air, dual duct VAV (with preconditioned outside air as hot deck), and multizone systems.

The refrigerant phase-out issue will emphasize reduction of the number of refrigerant sources on school facilities. This will reduce exposure by reducing the number of potential refrigerant sources of leaks. Consideration should be made to replace multiple DX equipment with new central chilled water systems. Heat can be recovered off chillers to provide source of heat for reheat. Also replacing small, individual constant volume air handlers with larger, VAV type air handlers can reduce the maintenance requirements of each air system. It is also more flexible in cases where facility loads may grow in the future.

Boiler plants were commonly used in schools in Florida until the 1980's. There has been a trend by maintenance departments to eliminate boiler systems and use electric strip heating since there is minimal maintenance. However, recent increases in demand charges and energy code requirements will probably again make boiler plants the preferred choice in the future. Hot water systems have excellent reheat applications. In addition, these systems are more flexible for growing campus needs.

SEMINOLE HIGH SCHOOL

Seminole County, Florida

A 13 million dollar project at Seminole High School included renovations to existing buildings and the addition of new classroom buildings and an administration building. The existing primary system was a four-pipe central chilled water and hot water system. Some existing buildings contained old DX units. *R. Douglas Stone Associates, Inc.* gave an indoor quality presentation to the owner to educate the staff on the merits of following *ASHRAE Standards 62-89* and *55-92* guidelines. In addition, the refrigerant phase-out issue was discussed. It was determined to expand the chiller plant capacity by replacing one of the existing chillers with a new 600 ton high efficiency centrifugal chiller (0.55 kW/ton) including a heat recovery heat exchanger. Both chilled and hot water systems incorporated primary/secondary pumping with variable frequency drives (VFDs) to conserve pump energy.

Air distribution systems included replacement of existing systems (fan coil, split DX, rooftop multizone, packaged constant volume) with central variable air volume (VAV) recirculating systems (no outside air) that modulate fan inlet vanes to maintain an optimized static pressure setpoint. (Limited budget did not allow VFDs.) Typical classrooms required 1,200 cfm of 55°F supply air for peak cooling conditions. Ventilation requirements were 15 cfm/student or 450 cfm per classroom. VAV boxes were the cooling only type, which modulate airflow based on room temperature in cooling or heating mode. Ventilation air was provided thru a dedicated outside air system which was designed to dehumidify outside air and supplement the cooling capacity of the VAV system. The system provided preconditioned outside air directly to each space at constant volume. The temperature setpoint was 55°F during peak conditions. If any VAV box was 100% closed and the space temperature was below the cooling setpoint, the ventilation air temperature was reset upward to maintain temperature in the current critical space. Temperature setup was performed using 110°F hot water reheat from waste heat scavenged from the new main chiller. Return water can be as low as 80°F, which can increase chiller efficiency slightly under some conditions.

Dedicated outside air systems allowed direct digital (DDC) system to shutdown the ventilation systems during unoccupied periods while allowing VAV systems to provide unoccupied temperature and humidity control. The DDC control system included humidistats in rooms and control sequences that actively monitor and control humidity and ventilation systems.

The total mechanical bid cost was 3 million dollars, or $2,365 per ton. This included extensive underground piping replacement ($400,000), DDC controls ($500,000) and chiller plant renovations ($150,000). The project was phased over a two year construction period, including after-hour work, which added approximately 20% to the total mechanical cost. Lighting incorporated standard ballasts with high efficiency fluorescent lamps. Unfortunately, an add alternate bid for electronic ballasts was not accepted by the owner due to budget constraints.

LIGHTING RETROFITS AND HVAC FINE TUNING

District School Board of Pasco County

One of the most ambitious efforts to improve the energy-efficiency of Florida educational facilities has been the effort of the District School Board of Pasco County. In 1992 Pasco County developed a comprehensive Energy Management Program. This has lead to an innovative effort where a revolving fund is being used to make retrofit efficiency improvements to the district's school buildings. Since Pasco County's energy committee estimates that approximately 35% of its energy use comes from lighting, the main emphasis thus far has been to improve these systems. Accomplishments in the 1993-1994 school year are summarized below:

- Relamped 3,000 incandescent exit signs at various schools using florescent retrofit kits. This is projected to save $22,000 annually.
- Replaced incandescent bulbs in 586 recessed can fixtures with compact florescents lamps. Estimated annual savings of over $7,300.
- Converted over 4,500 T-12 fluorescent lamps to either T-10 and T-8 lamp with electronic ballasts. Estimated annual savings of $81,000. The lamp replacements have resulted in a better perceived light quality and, in many cases, increased interior levels of illuminance.
- Added 500 spring-loaded AC timers added as well as automatic scheduling controls for HVAC systems.
- Upgraded equipment: replaced inefficient water heater, relocated thermostats for improved temperature control and adjusted outside air dampers for better ventilation performance.
- Conducted comprehensive educational energy awareness program for students and teachers. An extensive series of guidelines are used to promote efficient operation of the facilities. There is also an incentive program for the facilities showing greatest improvement in reducing energy costs and developing innovative ways to achieve the savings.

The one-time expense of the measures over the school year was $110K with an expected simple payback of only nine months. The impact of the improvements has already been observed in the county's monthly energy costs. Using the *Faser* energy-accounting software, the school system's 1993-1994 monthly energy use for the involved facilities decreased by an average of 9.7% over the previous year. The seasonally adjusted annual savings is predicted to be approximately $400,000 for the total improvements made over the two year history of the program. Furthermore, in spite of adding 38 portable classrooms, two new health clinics, a new music suite, an entire classroom wing and four walk-in freezers, the school board's energy bills actually decreased overall during the year! Even more impressive is the fact that the school district is planning to reinvest a portion of the savings in further improvements to its facilities as well as more efficient design of new construction. In this way, Pasco county's novel self-perpetuating program aims to achieve the most efficient school facilities in the state by the turn of the Century.

Contacts at the District School Board of Pasco County:

Michael Woodall, Energy Coordinator (813-929-2908)
Kenneth Trufant, Purchasing Agent (813-996-3600)

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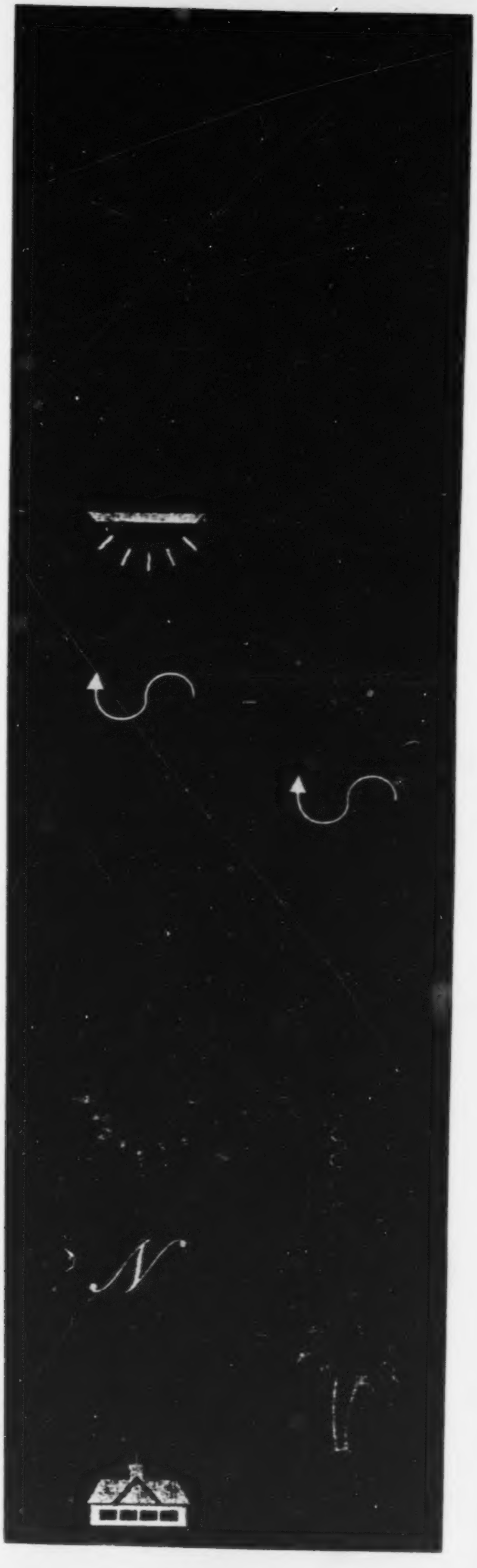

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Glossary

Altitude -- The position of the sun in the sky relative to the horizon, in degrees. At sunrise and sunset, the solar altitude is zero degrees. If the sun were directly overhead (possible only in the tropical latitudes), the altitude would be 90 degrees.

Azimuth -- The position of the sun in the sky relative to true south, in degrees. At solar noon, the sun is at zero degrees azimuth, and changes 15 degrees every hour. This difference is generally expressed in positive numbers for both east and west variations from south. Thus, both 11 a.m. and 1 p.m. are said to have a solar azimuth of 15 degrees.

Ballast -- A device used with fluorescent and other types of gaseous discharge lamps to aid starting, limit current flow, and to provide voltage control at proper design levels. Can be magnetic or electronic.

British Thermal Unit (Btu) -- Equal to the amount of heat energy necessary to raise the temperature of one pound of water one degree Fahrenheit. One Btu is about equal to the amount of heat given off by a wooden match.

Coefficient of Heat Transmission (U-Value) -- The overall U-value is the amount of heat transmittal from air-to-air in one hour per square foot of wall, floor, roof or ceiling for a 1°F temperature difference between the inside air and the outside air of the wall, floor, roof or ceiling. The lower the U-value, the less heat is transferred.

Coefficient of Performance (COP) -- The ratio of useful refrigeration obtained to the net work input. The ratio of the heat absorbed in the condenser to the difference of the heat rejected in the condenser and the heat absorbed in the evaporator [i.e., Btu (out)/Btu (in)].

Cooling Degree Days -- The annual sum of the number of Fahrenheit degrees of each day's mean temperature above 65°F for a given locality.

Cooling Load -- The amount of cooling (Btu/h) required to offset the rate of heat gain to the building at a steady-state condition when indoor and outdoor temperatures are at their selected design levels, solar gain is at its maximum for the building configuration and orientation, and heat gains due to equipment, infiltration, ventilation, lights, and people are present.

Glossary

Degree Day -- The degree day value for any given day is the difference between 65°F and the mean daily temperature. Example: for a mean daily temperature of 50°F, the degree days are 65 minus 50, or 15 degree days.

Demand Charge -- Charge for electrical service based upon customer's demand. It is a charge computed separately and distinctly from the energy charge.

Efficacy -- See Luminous Efficacy.

Emissivity -- The ability of a material to radiate absorbed heat.

Energy Efficiency Ratio (EER) -- The ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions.

Energy Utilization Index (EUI) -- The total energy consumption of a building (in Btu/year) per square foot of gross conditioned floor area.

Enthalpy Economizer -- Conditioning system in which outside air is used to meet HVAC needs when it falls within required temperature and humidity parameters.

Fenestration -- The design and placement of windows in a building.

Footcandle (fc) -- Energy of light at a distance of one foot from standard candle.

Heat Capacity -- The capacity of a given amount of a substance to absorb and store heat while experiencing a given temperature change. There are three standard measurements for heat capacity: *Specific Heat*, which relates to mass (Btu/lb°F); *Volumetric Heat Capacity*, which relates to volume (Btu/cu.ft°F); and *Thermal Mass*, which relates to a specific building element of known mass or volume (Btu/°F).

Heating Degree Days -- The annual sum of the number of Fahrenheit degrees of each day's mean temperature below 65°F for a given locality.

Heating Load -- The amount of heat instantaneously added or removed by the HVAC system. The rate of heat loss from the building at steady state conditions when the indoor and outdoor temperatures are at their selected design levels (design criteria). The heating load always includes infiltration and may include ventilation loss and heat gain credits for lights, equipment, and people.

Heat Transfer -- The measurement of heat from hot spaces to cooler spaces. There are three principal modes of heat transfer: *Conduction*, heat moves through a solid; *Convection*, heat moves by motion of a fluid or gas, usually air; and *Radiation*, heat moves from one body to another by heat waves without heating the air between the bodies.

Insolation -- The amount of solar radiation on a given plane. Expressed in W/m^2 or Btu/ft^2. One W/m^2 =0.317 Btu/ft^2.

Latent Heat -- The amount of heat necessary to change a give quantity of liquid to vapor at constant barometric pressure.

Lumen -- Unit of light energy or output (luminous flux).

Luminous Efficacy -- The ratio of the output of a lighting configuration in lumens to the total power input in watts. It is expressed in lumens per watt.

Peak-Hour Billing -- A utility billing scheme that rewards energy users who limit consumption during that part of the day during which the utility experiences its greatest demand. Generally, this is implemented by differential billing rates called demand charges. By limiting peak demand on its generation systems, a utility can forestall the construction of further generation capacity and operate its present plants at a more constant and efficient rate.

Relative Humidity (RH) -- A measurement, expressed as percentage, indicating the amount of water vapor in the air compared to the amount that the air could contain if it were completely saturated with moisture at the same temperature and pressure.

Sensible Heat Ratio (SHR) -- For HVAC equipment, the SHR is the fraction of the unit's cooling output (Btu/hr or tons) which is sensible. The lower the number, the better the moisture removal capacity of the equipment.

Shading Coefficient (SC) -- The percentage of available full-spectrum solar radiation that passes through a transparent or translucent object. A simple single-pane window assembly might have a SC of 1.0; a reflective window might have a SC of 0.5. The shading coefficient is an important glazing feature to consider when attempting to minimize heat gain through windows.

Simple Payback (SPB) -- Time required for an investment to pay for itself. The cost of the ECM divided by the annual energy cost savings in $/year.

Solar Absorptivity -- The fraction of incident solar energy that is absorbed by a material and results in a temperature increase of a surface or material.

Solar Reflectivity -- The fraction of incident solar energy (0.28-2.8 microns) which is reflected at the surface of the material.

Thermal Bridge -- An area of lower heat flow resistance within a larger area of greater resistance. An example would be an uninsulated 4-inch water pipe in a stud wall filled with R-11 insulation. A great amount of heat can flow through the highly conductive metal and water, defeating much of the benefit of the insulation on both sides.

Thermal Energy Storage Systems -- A refrigeration or heating system that produces and stores a cold or hot sink using off-peak electricity to reduce cooling or heating requirements during on-peak times.

Thermal Resistance (R-Value) -- The total thermal resistance is equal to the reciprocal of the overall coefficient of heat transmission (U-value).

Time of Use Rate -- Electric rate that varies as a function of the time of day. On-peak is usually between 11:00 a.m. and 6:00 p.m. when electric rate may be four times off-peak rate.

Transmissivity -- The fraction of incident solar energy which passes through a material and has no effect on the temperature of that material.

Ventilation Air -- That portion of supply air which comes from outside the building, as opposed to recirculated supply air.

Visible Light Transmission (V_T) -- The percentage of available visual-spectrum light that passes through a transparent or translucent object. This number is generally similar to the shading coefficient for a given glazing type, but can be either higher or lower depending on the specific properties of the glass. For daylighting purposes, a glass with a higher V_T than SC is desired because it admits visible light while blocking more of the solar heat gain.

Zoning -- The division of a building by expected or actual conditioning demand differences. For example, on a cold morning, the perimeter of a building may need heating, while at the same time the interior areas have built up heat from people and equipment and need cooling. The simplest zoning cases have five zones: north, east, south, west, and interior. Each zone is often treated differently in the scheduling and operation of its HVAC components.

Appendix A

Simulation

ENERGY ANALYSIS

The energy savings predictions in this manual were determined using a building energy simulation program which uses a computer model of the building and data on energy conservation measures (ECM) to predict annual energy use, energy cost, required cooling capacvity, peak loads, and a wide variety of other energy indicators. The quality of the program, the computer building model, and the ECM data determines the validity of the energy savings predictions. These are described in the following sections.

SIMULATION PROGRAM

The DOE 2.1D program used for the simulation work presented in this manual ranks high among energy analysis tools in the energy research industry. The U.S. Department of Energy developed the program in conjunction with the Lawrence Berkeley Laboratory.[8] A hardcopy of the Base Case Building input files used for these simulations is available from Janet McIlvaine at the Florida Solar Energy Center (see contact information, pg. 2).

BUILDING MODELS

A variety of input data is required to simulate the annual energy use of a building. these include physical and operational characteristics as well as weather data. The research team endeavored to accurately represent *current* facilities characteristics in each area of input.

Building type: Three building-types were modeled: classroom building, administration (office) building, and multipurpose building. In developing each of the three building models, the research team drew from a variety of sources including:

- State of Florida regulations for school construction
- Blueprints and specifications for recently built schools
- Conversations with operations staffs

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[8] A PC version of DOE 2 is available from ITEM Systems in Berkeley, CA. (510)549-1444 for the cost of about $700. Several other PC versions of DOE-2 are available. Mainframe versions of DOE 2 are available from the Simulation Group at Lawrence Berkeley Laboratory (510)486-4000.

- Discussion with designers and engineers involved with educational facilities

- Conversations with experts in building energy simulation.

Weather data: Each building was simulated using the weather data for 1989 for Orlando, FL (latitude 28.30, longitude 80.34, altitude 16). Beacuse energy use in educational facilities is dominated by internally generated loads, the variation of the weather conditions from North to South Florida is not as critical a parameter as it would be for an externally loaded building type, such as a residence. This is not intended to minimize the concern of those design teams building in climates other than central Florida. Time constraints however prevent the research team from executing all of the simulations for each section of Florida. However, the research team will be happy to produce runs (simulations) of any ECMs presented in htis text for a specific locaton within the constraints of available weather data.

Orientation: The long axis of all basecase models is aligned with the east-west axis. Major glazing areas face north and south. This bives the base case buildings the advantage of being well positioned for daylighting.

Materials and assemblies: The construction assemblies used for each model were the same:

Roof construction: Exterior finish of 3/8 inch built-up roofing (absorptance=0.75), R-11 rigid insulation (preformed mineral board) on quarter-inch deck with suspended acoustic tile. Deminision between roof top and ceiling finish is 3 feet.

Walls: Exterior walls are 4-inch medium-colored face brick (abs=0.60), air space, R-3 rigid insulation (expanded polystyrene), hollow lightweight concrete block, and air space (3/4-inch or less). The interior wall finish is gypsum or plaster board. Metal exterior doors have construction U-value of .25.

Glazing: All windows are 1/8-inch single pane clear. The glass has a shading coefficient of 1, visible light transmittance of .90, and glass conductance of 1.1.

Floor: Concrete slab with carpet and rubber pad.

Interior Conditions: Various interior characteristics must be defined; here, the three building types varied widely since activity, spatial characteristics, and occupancy varied. However, the three shared the following:

Occupancy: Base Case Building occupancy was assumed for the school year schedule from 7am-4pm. Some occupancy was modelled for summer and evening hours. Infiltration is defined at .35 ACH in the interior and plenum spaces.

Conditioning Set Points: The heating set points were 50 degrees (midnight to 6am) 72 degrees (6am-4pm), 65 degrees (4-6pm), 55 degrees 6pm-midnight). For weekends and holidays the heating set point was assumed to stay at 55 degrees 24 hours a day. The cooling set points were 90 degrees (midnight-6am), 76 degrees (6am-4pm), 85 degrees (4pm-6pm), and 90 degrees (6pm-midnight). For weekends and holidays, a setting of 90 degrees was maintained 24 hours a day.

Spatial characteristics:

Classroom building: The classroom building contains two rows of exterior-access classrooms (27 ft * 35 ft each) and a small core area for storage and/or office spaces (12 ft * length of building) between the two rows.

Administration building: The administration building houses a variety of private or semi-private offices, work and conference rooms, a break room, a supply room, a reception area and a library.

Multipurpose building: The multipurpose/assembly building consists of a dual use cafeteria-auditorium space with a kitchen at one end of the building and a stage (and storage) area at the other end.

Hypothetical campus: A campus composed of Base Case Building types would include one multipurpose building, one administration building, and 6 classroom buildings.

ENERGY CONSERVATION MEASURES

Simulating ECMs requires the research team to determine how an ECM affects the physical and operational characteristics of the building. For each ECM, parameters in the Base Case Building input deck must be changed.

How does one know what to alter and how much to change it? If the simulation input data for an ECM does not agree with reality, the energy savings predictions will obviously be biased and misrepresentative.

As a consequence, the research team has endeavored to represent accurately the savings potential of various measures. This information was gleaned, whenever possible, from field or laboratory research data. When uncertainty existed, the research team selected conservative values for estimating the ECM benefits. The input changes for each ECM are documented in the following tables.

MEASURE	CHANGED PARAMETER	SOURCE OF DATA*
Non-Optimal Orientation	Rotated building 90° Long axis aligned with the North-South axis	3
Single Pane Reflective Glazing	SC = 0.51, VT = 0.27, gc = 1.12	1
Double Pane Clear Glazing	SC = 0.89, VT = 0.82, gc = 0.50	1
Double Pane Reflective Glazing Bronze	SC = 0.42, VT = 0.26, gc = 0.5	1
Double Pane Spectrally Selective Glazing	SC = 0.36, VT = 0.61, gc = 0.33 Daylight "OFF", 1.4 W/sq.ft.	4
Ceiling Fans	Raised cooling set point 2 degrees Raised equipment load 40 W per fan	5
4 Foot Overhang	Added 4 foot building shade on all sides	5
Shade Trees	Added building shades to the East, West, and South sides of building to simulate shape of mature live oak	Florida Energy Extension Service
Roof Insulation (R-30)	Changed roof insulation R-value to 30	3
Reflective Wall Finish	Changed wall absorptance from 0.6 to 0.4	4
Light Shelves	Added buildind shades with 75% top reflectivity at 1/3 the height of the window from the top of the window on the South facade	This simulation does not reflect the complete effect of a lightshelf.
2 Foot Overhang (roof)	Added 2 foot building shade on all sides	3
R-11 Wall Insulation	Changed wall insulation to R-11 (rigid to exterior of blocks)	3
R-19 Wall Insulation	Changed wall insulation to R-19 (rigid to exterior of blocks)	3
Interior Insulation	Moved wall insulation to interior of construction	3

MEASURE	CHANGED PARAMETER	SOURCE OF DATA*
32 Watt T-8 Lamps Electric dimming ballast Parabolic troffer with reflector Prismatic diffuser	Daylight "YES", Lighting W/sq.ft. = 1.06	2
32 Watt T-8 Bulbs Electronic ballast Parabolic troffer Open diffuser	Lighting W/sq.ft. = 1.06	2
34 Watt T-12 Bulbs Magnetic ballast Parabolic troffer Open diffuser	Daylight "OFF", 1.38 W/sq.ft.	2
40 Watt T-12 Magnetic dimming ballast Parabolic troffer with reflector Open diffuser	Daylight "YES", W/sq. ft. = 1.18	2
40 Watt T-12 Magnetic ballast Parabolic troffer with reflector Open diffuser	Daylight "OFF", 1.52 W/sq.ft.	2
Occupancy Sensors	Reduced lighting watts per sq. ft. by 15%	6
LED Exit Signage	New lighting wattade from 40 W/single sided exit sign to 4.5 W	4 Alternation Energy Corp. Pub #
Centrifugal Chiller	Changed chiller type = open-vent-chlr	3
Screw Chiller	Changed chiller type = HIR, EIR, CAP = Quadratic Curve Fits	3 DOE2.1D sample run book under direction of Bruce Birdsall
Gas Absorption Chiller	Changed chiller type - single stage absorption chiller	3

MEASURE	CHANGED PARAMETER	SOURCE OF DATA*
Variable Speed Pumps	CCIRC-Pump-Type = Variable-Speed HCIRC-Pump-Type = Variable-Speed	3
Non-Variable Speed Fans	O/A Control = Fixed	3
Variable Temperature Constant Volume	Changed System Type to SZRH	3
Multizone Constant Volume	System Type = MZS	3
Dual Duct Constant Volume or Variable Volume	System Type = DDS	3
Four Pipe Fan Coil	System Type = FPFC	3
15 cfm per person ventilation rate	OA CFM = 15	3
Total Energy Recovery System for 5 cfm ventilation rate	OA CFM=2	Simulations of sensible and latent heat recovery performed by K. Rengarajan, Florida Solar Energy Center
Total Energy Recovery System for 15 cfm ventilation rate	OA CFM=6	
Optimal Start (Energy Management System)	Cooling Set Point Schedule on weekdays =-999 for start hours	3
Enthalpy Economizer	OA Control = enthalphy Econo limit T=50	3 Consultation with Brian Cumming, R. Douglas Stone Associates, Orlando, FL.
Reheat Constant Volume	System Type = RHFS Max - humidity = 60 Reheat - delta-T = 55	3
Unitary Heat Pumps	System Type = HP	3
Packaged Single Zone Variable Temp Dx Unit	System Type = PMZS Heat - source = electric	3

MEASURE	CHANGED PARAMETER	SOURCE OF DATA*
Packaged Multizone Dx Unit	System Type = PSZ Heat - source = electric	3
Packaged Terminal AC/Heat Pump	System Type = PTAC Heat - source = electric	3

* 1 = Parker, 1989; 2 = Parker, et.al., 1994; 3 = DOE2.1D Manuals; 4 = Manufacturer data; 5 = Discussion with energy simulation experts; 6 = Educated guess

FURTHER QUESTIONS

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